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An Environmental Assessment of Northern Puget Sound and the Strait of Juan de Fuca

A Summary

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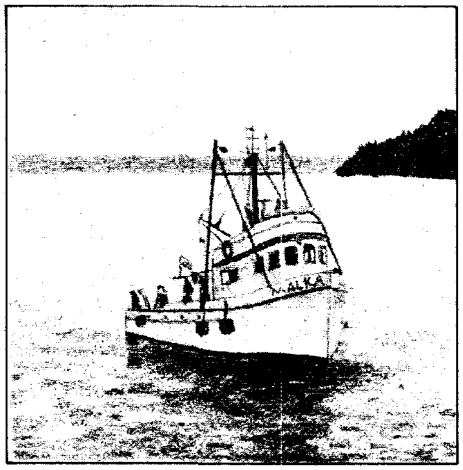

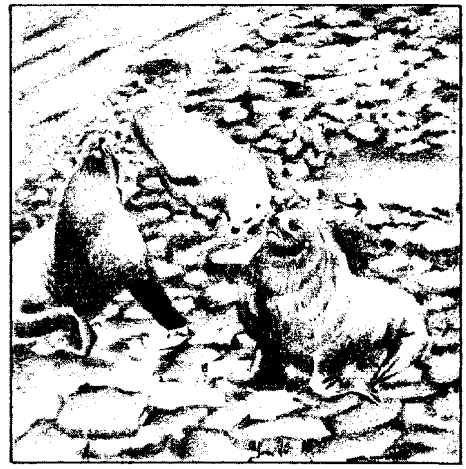

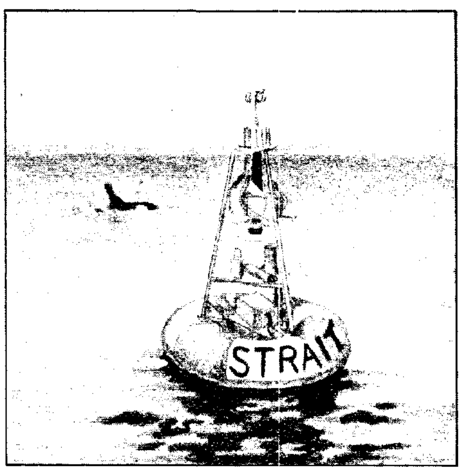

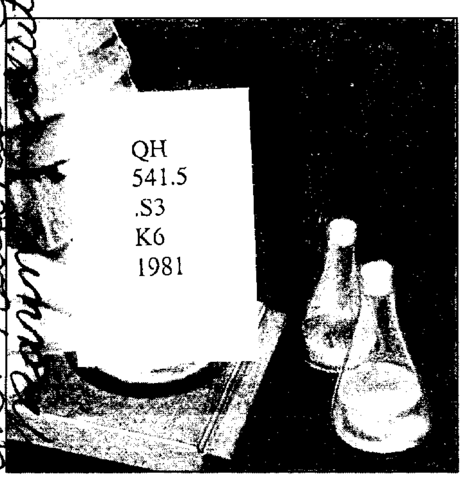

AN ENVIRONMENTAL ASSESSMENT OF NORTHERN PUGET SOUND AND THE STRAIT OF JUAN DE FUCA

A SUMMARY

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and
Edward R. Long

NOAA/OMPA
Seattle, Washington

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UNITED STATES DEPARTMENT OF COMMERCE
Malcolm Baldrige, Secretary

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
John V. Byrne, Administrator

Office of Marine Pollution Assessment
R.L. Swanson, Director

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INTRODUCTION

Overview

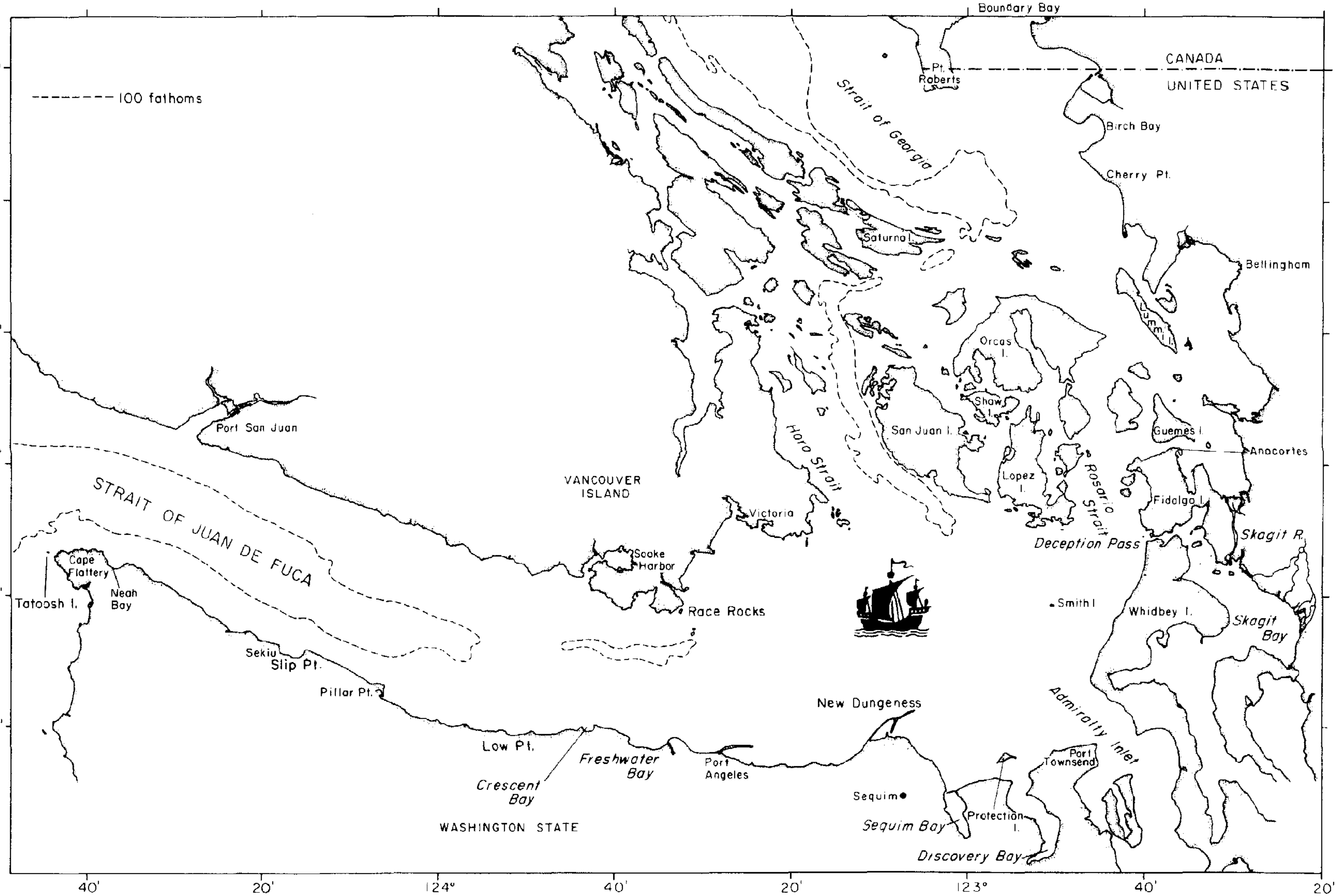
The Environmental Assessment of Northern Puget Sound and the Strait of Juan de Fuca was a five-year research project to address the potential marine environmental and ecological consequences of the intensified petroleum-related activities anticipated for the next decade in the Puget Sound region. Initiated in 1975, the Project was one of many funded by the U.S. Environmental Protection Agency (EPA) to provide the information needed to identify and cope with the impact of the nation's accelerated development of its energy resources. This research was administered by the National Oceanic and Atmospheric Administration's MESA (Marine Ecosystems Analysis) Puget Sound Project Office located in Seattle, Washington.

The purpose of this research program was to measure and characterize the major environmental components and processes of the region, such that the results could be used in planning future petroleum-related activities, in minimizing damage that may be caused by any oil spills, and in assessing any oil spill damage that may occur. Existing levels of petroleum hydrocarbons in the marine environment were observed as were the physical, chemical, and biological mechanisms that play an important role in dispersing and removing oil from the marine environment. Tides, winds, and water circulation were studied to determine where a potential oil spill would go and what shoreline areas could be impacted. A computer oil-spill trajectory model and a regional wind model were developed to guide and assist oil-spill response teams and clean-up crews. Shoreline areas were studied and mapped in detail and rated to determine their sensitivity to oil spills and their capacity to recover. High priority was given to inventorying and characterizing the major marine biological populations, including the birds and mammals, that could be affected by oil pollution. Also, the processes such as loss of oil, recolonization and rates of recovery of biota from a simulated spill were documented. The effect of oil upon typical biota of the Northwest coast was not investigated, since other NOAA projects were addressing this problem concurrently.

A dedicated effort was made to seek out, analyze, and to synthesize all relevant information in order to avoid any duplication of efforts and to identify and fill in any serious gaps in our knowledge. These data, as well as Project-generated data, reside on magnetic data tape and are retrievable as simple tape copies, printouts, and in a variety of other forms to meet user needs and requirements. Some of these data were closely examined with statistical methods to determine their utility in assessing oil spill damage. Special publications and products and public meetings provided industry, concerned citizens, and Federal, state, and local agencies with important information about Project activities and findings. Much of the Project research was incorporated into the Bureau of Land Management's (BLM) Environmental Impact Statement distributed for comment in January 1979 concerning crude oil transportation systems, especially terminals and pipelines, for the Puget Sound region. Many of the Project's principal investigators have participated in public meetings and seminars and have been interviewed by the media. Many of these same scientists provided expert testimony at hearings conducted by the Washington State Energy Facility Site Evaluation Council (EFSEC) in Olympia on siting of crude oil terminals and pipelines.

The results of Project-supported research are contained in numerous technical reports and papers listed in the Products section and reflect a broad contribution from Federal, state, and academic institutions and private firms. The detailed information contained in these technical reports was written mostly for biologists, chemists, oceanographers, and other technical specialists.

The objective of this report is to summarize the large body of technical information and to communicate the major findings and ideas to the general public. Only those major results that appeared to be of greatest general interest to the public were extracted from the technical reports and included here.



The Strait of Juan de Fuca and northern Puget Sound.

Strait of Juan de Fuca and Northern Puget Sound

Historians credit, with some degree of skepticism, the discovery of the Strait of Juan de Fuca to a Greek navigator named Apostolus Valerianos. Apostolus, who purportedly spent 40 years sailing under the Spanish flag, was better known to his employers and shipmates by his Spanish alias, Juan de Fuca. The story goes that after piloting the Spanish exploration vessels from Mexico into the Strait of Juan de Fuca in 1592, he returned to Spain to proclaim discovery of the much sought after Northwest Passage and to await honor, fame, and fortune. Unfortunately for de Fuca, he was scoffed at and his discovery rejected for nearly 200 years before its rediscovery by Captain Charles Barkley of the English Navy in 1787. Captain John Meares of the English Navy verified Barkley's discovery a year later and thus became the perpetrator in the naming of the Strait of Juan de Fuca, for in his ship's log Barkley proclaimed, "We shall call the (Strait) by the name of its original discoverer, Juan de Fuca."

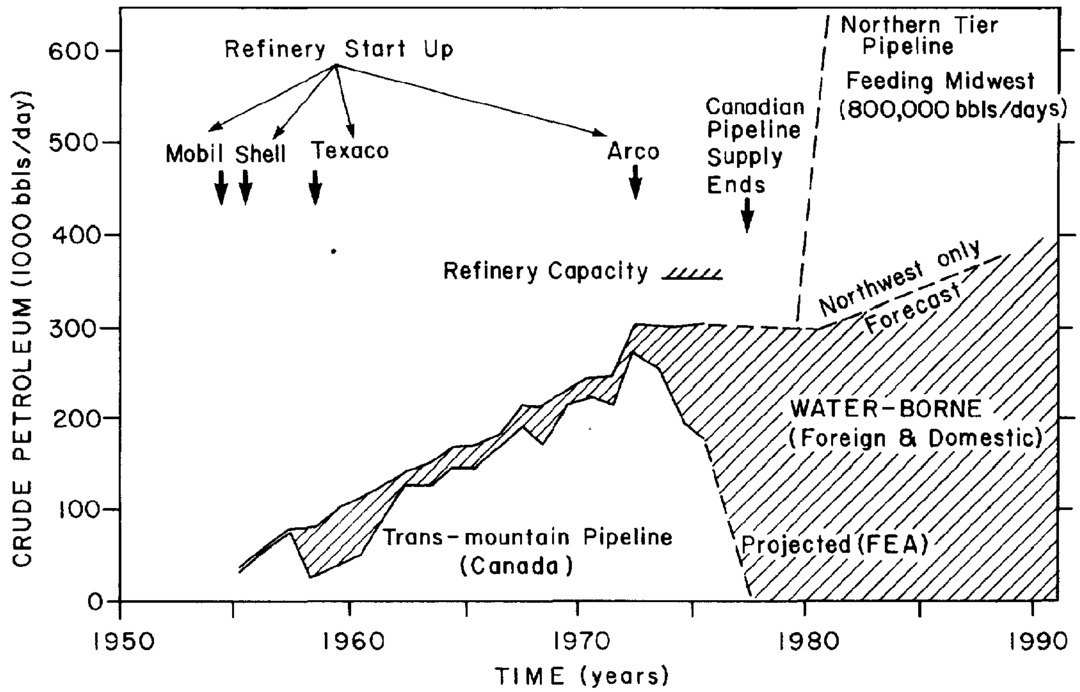
The northern Puget Sound region, as used in this report, is that area northwest of Whidbey Island, extending northward through the San Juan Islands to the Canadian border. Although Juan de Fuca may have sailed through this area into the strait of Georgia, credit for the discovery of the northern Puget Sound region in 1791 went to Lopez Gonzales de Haro who was under the command of Spanish explorer Francisco de Eliza. Eliza worked for the viceroy of Mexico, one Señor Don Juan Vicente de Güemes Pacheco de Padilla Horcasitas y Aguayo. Whether to honor his employer or to assure future patronage, Eliza chartered the island group as Isla y Archiepelago de San Juan. Headquartered on Vancouver Island, Eliza and his colleagues—Salvadore Fidalgo, Jacinto Caamaño, Cayentano Valdés, and Dionisio Alcalá Galiano—explored the island group for the next two years. Next came the British with some new discoveries and new names as well as rediscoveries and renaming of Spanish discoveries. This process was repeated by Charles Wilkes of the U.S. Navy and Commander of the U.S. Exploring Expedition of 1838-1842. A worshipper of naval heroes of the War of 1812, Wilkes named his discoveries after distinguished officers of the war such as Shaw, Decatur, Blakely, Sinclair, and others. Thus the waters and lands of the region reflect the Spanish-English-American influence in addition to that of the original inhabitants, the native American Indian.

Geographically, the Strait of Juan de Fuca is a glacially-formed submarine valley extending about 80 miles from its Pacific Ocean entrance at Cape Flattery eastward to the San Juan Archipelago. The Strait is bounded by the more than mile high Olympic Range on the south and the Seymour Range to the north where elevations exceed 3,900 feet. From its entrance near Cape Flattery for about 50 miles eastward to Race Rocks, the Strait is about 12 miles wide with relatively steep sides, its U-shaped channel being testimony to the glacial forces which helped to sculpture it. In the next 30 miles, the Strait widens abruptly to around 16 miles. Depths exceed 840 feet in mid-channel off Cape Flattery and decrease gradually for around the next 37 miles to 600 feet. This gradual decrease in depth continues into the eastern portion, or basin, of the Strait where the bottom topography becomes more complex with deep channels separating numerous shoals and banks. In this eastern basin, the Strait joins to the north Haro and Rosario Straits and the passages through the San Juan Islands which, in turn, join the Strait of Georgia. Another major arm branches to the southeast through Admiralty Inlet to join the central basin of Puget Sound. A lesser branch in the northeast corner joins Skagit Bay through Deception Pass.

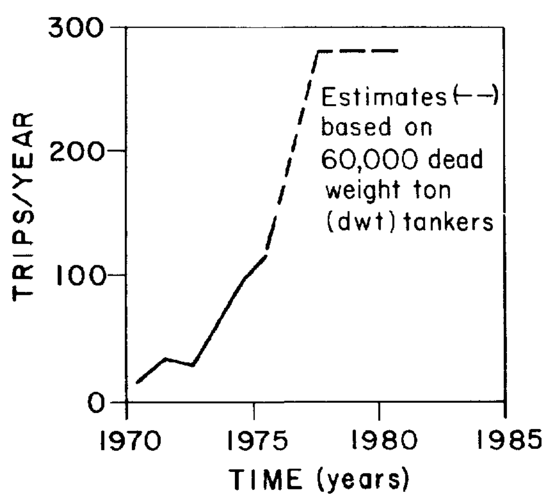
The Problem

Prior to the mid 1970's, the Puget Sound region was never a busy petroleum center. Only enough crude oil, around 300,000 barrels per day, was imported and refined to supply the traditional market of the Pacific Northwest comprising Washington, Oregon, and Idaho. And, since the major portion of this amount was supplied via a pipeline from Canada, there was historically only minor shipping of petroleum and petroleum products through the area's waterways. Events started to unfold in 1968 which later would begin to focus on the Puget Sound region and to raise concerns of the threat of oil pollution to marine economic, recreational, and aesthetic interests.

The search for a system to carry Alaskan crude oil to market was begun in 1968 when the largest crude oil reservoir in the Western Hemisphere was discovered at Prudhoe Bay on the North Slope of Alaska, at the edge of the Beaufort Sea. By the end of 1972 numerous alternatives on ways to distribute the oil to the lower 48 states had been suggested and evaluated. One major alternative important to the Puget Sound region



Crude petroleum inbound to Puget Sound (waterborne and pipeline) as projected in 1975.



Incoming crude petroleum tanker trips on Puget Sound.

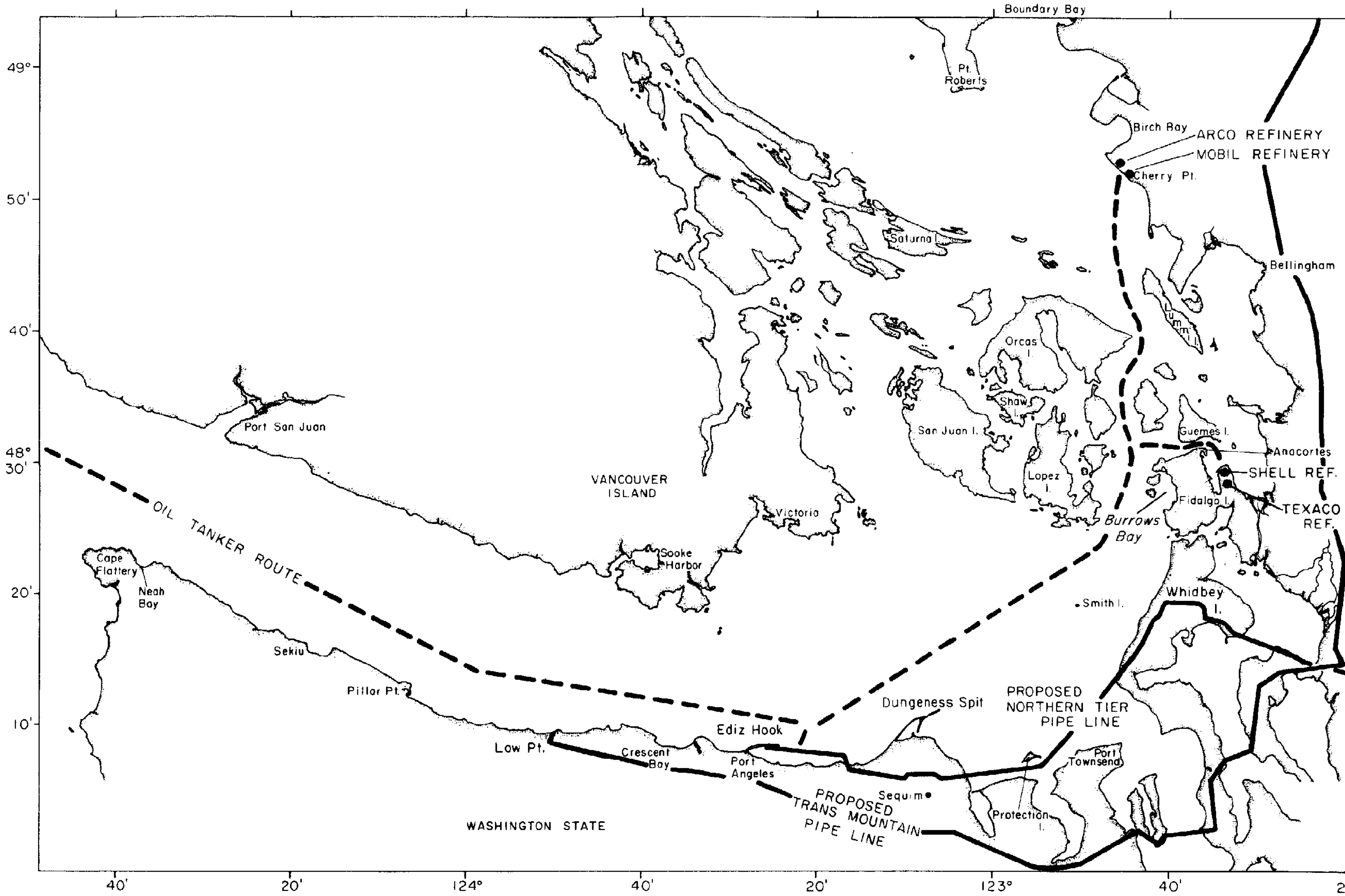
involved new pipelines from the U.S. West Coast to markets east of the Rockies. Because of its closeness to the terminus of the Trans-Alaska Pipeline at Valdez, Alaska, and an abundance of deep harbors, the Strait of Juan de Fuca harbors and nearby ports were envisioned as potential crude oil superports. Recognition would later come to places, among others, like Port Angeles, Low Point, Freshwater Bay, Cherry Point, and Burrows Bay, as candidates for a proposed terminal and starting point of a pipeline to carry crude oil eastward to refineries in Minnesota.

In 1974, another event occurred which directly affected the amount of crude oil moved on Washington waters and stimulated and intensified the issue of a west-to-east pipeline. Historically, a large share of U.S. crude oil imports supplying the Northern Tier States of Washington, Oregon, Idaho, Montana, North Dakota, Minnesota, Michigan, Wisconsin, Illinois, Indiana, and Ohio came from Canada. The volume imported from Canada was averaging around 800,000 barrels per day. The imported crude oil entered the United States through pipelines from Canada to Washington, Montana, North Dakota, and Minnesota. In late 1974, the Government of Canada announced plans to reduce and eventually curtail exports of crude oil to the United States by 1981. Many U.S. refineries using Canadian crude were located in Illinois, Indiana, and Ohio where supply alternatives existed through pipelines extending from the Midwest, Southwest, and Gulf Coast. However, some refineries in the Northern Tier area had no satisfactory alternative sources of crude oil. The Federal Energy Administration (FEA), now the Department of Energy (DOE), established an allocation program that gave first priority to those Northern Tier refineries most dependent on Canadian oil. In addition, the FEA determined that major refineries in the Puget Sound area of Washington located at Cherry Point, Ferndale, and Anacortes, could receive crude oil by tanker to replace Canadian imports and thus ordered that Canadian shipments to Washington be completely phased out by 1977. This action would require the supplying of Washington refineries solely by more or larger tankers, or both.

During the planning and early construction stages of the Trans-Alaska Pipeline, the expected pipeline flow was not anticipated to exceed present West Coast demand. At that time, crude oil prices had remained relatively stable since the 1950's, and until 1970 the major oil producing states had held production below full capacity. Low-cost foreign crude overshadowed the world petroleum market. However, the nation's demand for petroleum and refined products, which had been increasing, dropped sharply due to high prices and conservation after the 1973 oil embargo. With steadily declining demand, it became clear shortly after the Trans-Alaska Pipeline started production in 1977 that a surplus of Alaskan crude oil would occur on the West Coast. By 1978, the volume of Alaskan crude oil reached about 1.2 million barrels per day; this created a surplus of about 600,000 barrels per day on the West Coast. The surplus was shipped via tanker through the Panama Canal to ports on the Gulf of Mexico and the East Coast. In addition, large supertankers which were capable of transporting more oil longer distances at a cheaper per-barrel transportation cost than had previously been possible were being placed into service. These tankers, however, needed off-loading ports with deep waters and room to maneuver. The West Coast had deep water—in Washington, Oregon, and California—and the ports had room and space to accommodate the new tankers.

The search for a crude oil transportation system to deliver Alaskan and other crudes from the Pacific Coast to the Northern Tier and inland states recently has narrowed to the Puget Sound region, especially the Port Angeles and Low Point areas on the Strait of Juan de Fuca. Proposed crude oil terminal sites such as Cherry Point, Anacortes, Burrows Bay, and other locations in Washington were considered and rejected for various reasons. Long Beach, California, initially a strong candidate, was also withdrawn from consideration.

Four companies have filed applications with the Secretary of Interior to construct and operate a crude oil terminal and transportation system. Only two directly affect the Puget Sound region. The Northern Tier Pipeline Company proposes to build a marine terminal at Port Angeles and to lay about 1,500 miles of new pipeline to Clearbrook, Minnesota. The Trans Mountain Oil Pipe Line Corporation proposes to build a marine terminal at Low Point with 150 miles of new pipeline in the State of Washington to ultimately connect to existing lines from Edmonton, Alberta, to the Midwest states. The Department of Interior's Bureau of Land Management (BLM) has completed Final Environmental Impact Statements covering all four applications. In addition, the two companies (Northern Tier and Trans Mountain) have applied to the State of Washington for the necessary permits and approval for construction. Both applications included underwater pipeline crossings near or in Admiralty Inlet, though when the Project was initiated, no underwater crossing was planned.



Oil tanker routes to refineries and Northern Tier Pipeline Company and Trans Mountain Pipe Line Corporation proposed crude oil pipeline routes.

APPROACH

Interagency Energy/Environment Research and Development Program

Although the Federal Government has been a major sponsor of energy research and development since the early 1950's, environmental considerations associated with energy development did not receive major public visibility until the early 1970's. During that period, the Federal Government's major emphasis was on the development of nuclear power. Also at that time, energy was plentiful and cheap, and the process of initiating and utilizing ecological information in the planning and development of energy resource-oriented projects was just beginning to ferment. The Federal Government's role was seen as a limited one, for the nation believed that industry would provide the solutions to the country's energy needs. The underlying assumption of this belief was based on the then widely prevalent view that the nation had nearly inexhaustible domestic oil and gas resources. The Mideast War and subsequent oil embargo of 1973 shattered this belief and helped to intensify the Nation's awareness of and concern about environmental problems associated with rapid energy development.

As events began to unfold in the Mideast in early 1973, public and congressional pressure began to build for a solution to the long gas lines and crude oil shortages. In June, the President directed the Chairman of the Atomic Energy Commission (AEC), Dixie Lee Ray, to recommend an integrated energy research and development program for the nation. The AEC report "The Nation's Energy Future" (often referred to as the Ray Report) was completed in December 1973. That program, based upon the work of 23 Federal departments and agencies, as well as many experts from the private sector, recommended a five-year, $10 billion Federal energy research and development budget. The report identified five tasks (related to energy conservation, oil and gas, coal, nuclear energy, and advanced energy resources) required to support the goal of "regaining and maintaining energy self-sufficiency at minimum dollars, environmental, and social costs." In addition, a supporting environmental effects research program was recommended. On the basis of the AEC report, the President's budget for Fiscal Year 1975 requested funding through the budget of the Environmental Protection Agency for the expanded Federal effort in energy/environment research and development.

In early 1974, two Federal task forces were formed by the White House Office of Management and Budget under direction of the Council on Environmental Quality to develop recommendations for implementing the program based on the AEC report. The two interagency task forces were to recommend how the Federal funds requested by the President through the EPA could be allocated to support the most effective Federal energy research and development program. The two groups examined the areas of health and environmental effects of energy use and pollutant control technology for energy systems. Their reports recommended Federal funding in these two areas which would result both in closing existing research gaps and eliminating duplications of effort and in assessing potential long-range effects, or adverse health and ecological effects, of rapid energy development.

Based on the recommendations and guidance contained in the AEC report and the reports of the two working groups, the Interagency Energy/Environment Research and Development Program was inaugurated in 1975. The task of implementing this five-year, multimillion dollar interagency plan fell to the Office of Energy, Minerals, and Industry within the Environmental Protection Agency's Office of Research and Development. This massive effort became known as the Federal Interagency Energy/Environment R&D Program. EPA was given legal responsibility for the proper disbursement, monitoring, and control of the financial resources it transferred, or passed-through, to the 17 Federal agencies that participated in this program. This R&D program is still in progress.

Research and development under the Interagency Energy/Environment R&D Program was separated into two groups: *Processes and Effects* and *Control Technology*. Five categories in the Processes and Effects R&D group include efforts to determine what a pollutant is, how it travels through the environment, how much is present, at what level it is dangerous to humans and to other living things, and what is its overall impact on all segments of the energy/environment complex. The Control Technology R&D group includes nine categories related primarily to the production and utilization of coal and to nuclear energy. The Ecological Effects category in the Processes and Effects group is of special significance to the Puget Sound region. Ecological Effects R&D is concerned with the potential short- and long-term effects of energy development and use on crops, plants, wildlife, and natural habitats. In the Puget Sound region, this program research effort relates to potential energy-related environmental problems in ocean, coastal, and estuarine ecosystems resulting from increased tanker traffic, petroleum transfer operations, and refinery capacity.

INTERAGENCY RESEARCH AND DEVELOPMENT CATEGORIES	
PROCESSES AND EFFECTS	CONTROL TECHNOLOGY
Characterization, Measurement & Monitoring	Energy Resource Extraction
	Physical/Chemical Coal Cleaning
Environmental Transport Processes	Flue Gas Cleaning
	Direct Combustion
Health Effects	Synthetic Fuels
	Nuclear Waste Control
Ecological Effects	Thermal Control
	Improved Efficiency
Integrated Assessment	Advanced Energy Systems

FINDINGS

This Project, An Environmental Assessment of Northern Puget Sound and the Strait of Juan de Fuca, resulted in the publication of more than 100 technical reports, papers, and special publications listed in the Products section. A few other reports have yet to be issued, and it is expected that additional information will be gleaned from the reports and data in the course of future and related research.

Much of the material contained in the published literature is highly technical and difficult to understand without extensive training in one or more scientific disciplines. This section on Findings, on the other hand, attempts to summarize and communicate this technical literature to the general public.

The section is organized into a number of statements followed by an explanation, brief rationale, or argument in support of each statement. The statements are based on facts and conclusions presented in the technical literature as well as from expert testimony given by Project-sponsored researchers at Washington State Energy Facility Site Evaluation Council (EFSEC) hearings in Olympia, Washington, concerning the Northern Tier Pipeline Company's application for site certification for an oil port at Port Angeles and a pipeline across the State of Washington. In some cases the statements are simply the rephrasing of concerns expressed by environmental administrators, planners, and concerned citizens. No attempt was made to cite references in this report. Instead, the reader is encouraged to consult the literature in the Products section for further information and discussions.

The statements in this section are arranged in the following order: (1) the present level of oil pollution in the area, (2) the chemical changes that may occur to oil if it were spilled, (3) the processes that may disperse and transport oil, (4) the biota that may be affected by oil spills, (5) the relative sensitivity of various habitat types to oil spills, (6) the effects of oil upon and the rates of recovery of oiled communities, and (7) the utility of the environmental data in assessing oil spill damage. These topics are generally in the order of concerns expressed during an oil spill. That is, during a spill one would worry about how much oil is in the environment now, what will happen to spilled oil, where will it go and what plants and animals are likely to be impacted, what areas should be protected, how long will recovery take, and what damage was caused?

The biota of the area are not now stressed by petroleum hydrocarbons.

Petroleum-related activities currently take place in the region and likely result in the entry of some amount of oil, or petroleum hydrocarbons, into the marine environment. Thus, it is reasonable to expect that some parts of the region have some oil contamination, but that most of the region is oil-free. How much oil is in the marine environment now and where is it? In order to answer these questions, a pilot study was initiated to determine the best way to perform an areawide survey. An approach involving sampling and chemical analysis of beach sediment and mussels was developed. The sediment samples were intended to provide long-term accumulation information, while the mussels would provide short-term or recent oil-contamination levels.

Samples of beach sediment and mussels were taken each season for a year at 23 sites throughout the area and at 10 of these sites for another year. Concentrations of petroleum hydrocarbons in these samples were found to be relatively low, far below what would be expected in highly industrialized areas or where spills continually take place. For example, the concentrations of selected aromatic hydrocarbons (one class of compounds that is a major component of oil) rarely exceeded 20 parts hydrocarbons per billion parts sediment (ppb). Hydrocarbon concentrations in mussel tissue rarely exceeded 200 ppb. In contrast to these concentrations, marine sediments near Tacoma and Seattle are known to contain many thousands (for example, over 50,000) ppb. Among the 23 sites, the highest concentrations were found at March Point near the Anacortes refineries, at Sandy Point near a marina, False Bay on San Juan Island, Ediz Hook at Port Angeles, and Baadah Point near Neah Bay. From these data, it is safe to assume that the biota in the area are not stressed by oil pollution, except, possibly, in highly localized areas.

Oil spilled in the Strait of Juan de Fuca, especially in the eastern part, could transit Admiralty Inlet into Puget Sound.

Crude oil is a complex mixture of natural products and includes many thousands of different compounds. The composition of crude oil can vary widely from one producing field to another and can even differ from batch to batch in the same well. What happens to crude oil in Puget Sound waters depends to a great extent on the composition of the oil and the physical and chemical changes the oil undergoes in the marine environment. Biological processes also play an important role in determining the fate of petroleum.

When crude oil is spilled in marine waters, physical and chemical processes begin to react immediately. These processes include spreading to form slicks, evaporation of the more volatile components, solution of some compounds into the water column, emulsification, photochemical oxidation, and sedimentation. To see how oil could transit Admiralty Inlet from the Strait of Juan de Fuca, it is necessary to examine some of the physical and chemical processes acting to disperse and transport a potential oil spill and the physical oceanography of the region.

Oil immediately begins to spread when released on the water's surface, and its rate of spreading is determined to some measure by its chemical composition. The spreading slick will be shaped and moved by surface currents driven by tides, wind, waves, and other forces. Some compounds in the oil will pass into solution and be incorporated into the water column. Oil can also adsorb onto particles. As a result of this process, particles become denser or heavier than the surrounding water, and they can sink to water levels that equal their density or to the bottom.

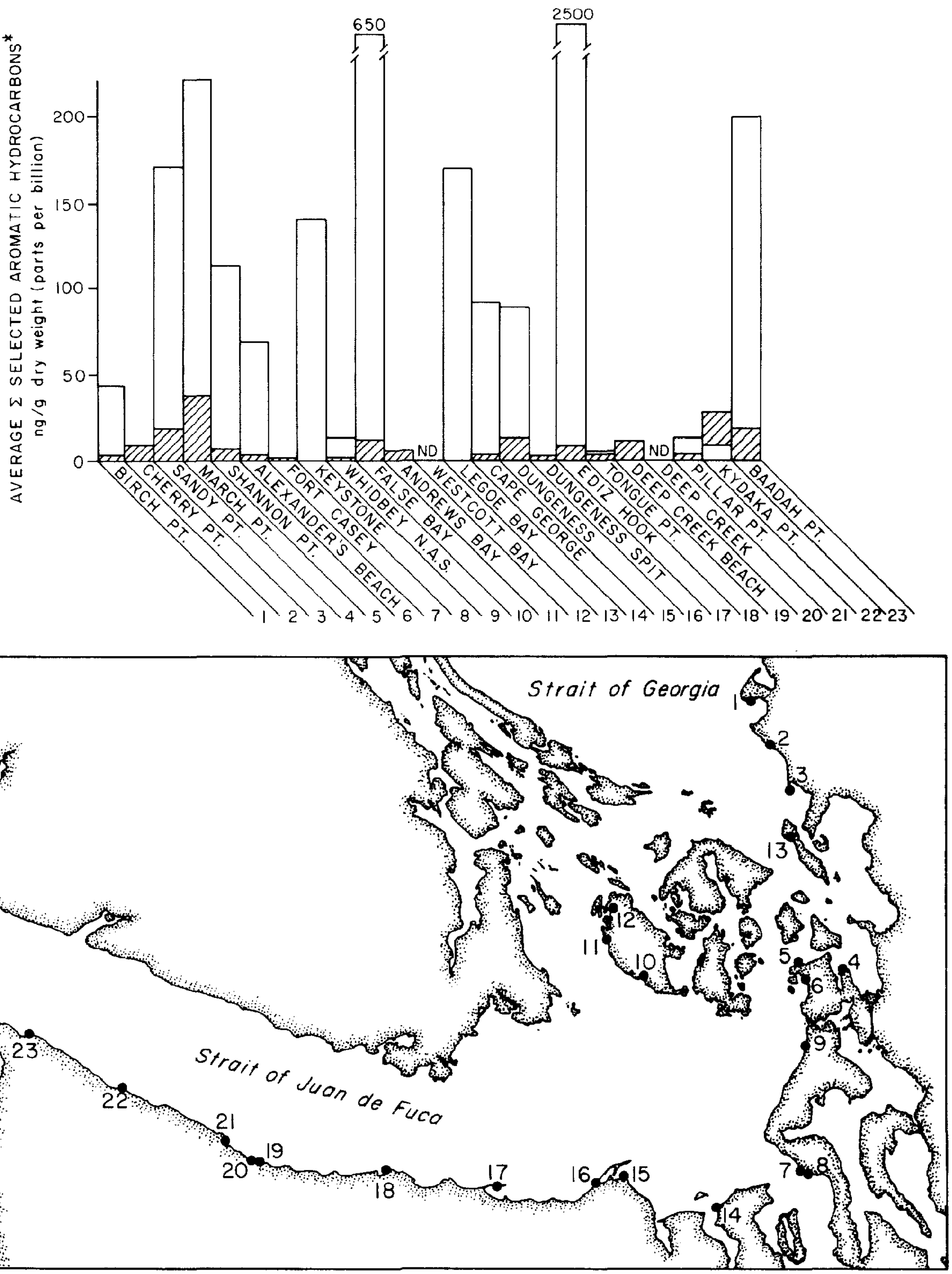
Circulation in the Strait of Juan de Fuca has been shown to be extremely complex and energetic, especially in the eastern basin and near the entrance to Admiralty Inlet. A sill, or underwater ridge, in Admiralty Inlet results in vigorous vertical mixing throughout the water column. During a strong flood tide, an oil slick introduced at the north entrance of Admiralty Inlet could be carried on the surface into or through Admiralty Inlet, the extent of travel determined by the strength and duration of the flood current. In contrast to the behavior of a surface slick, suspended and soluble pollutants during a strong flood tide could be transported through Admirlty Inlet to mid and bottom depths in the deep basin to the south. The intruding water would tend to seek a depth at which its density equals that of the resident water. Since the net estuarine flow in these lower layers is southward, pollutants trapped in these waters would be expected to travel southward to the head of the system in Puget Sound.

Elsewhere in the Strait of Juan de Fuca, researchers have observed numerous rips and frontal zones at the water surface where floatable materials often collect. These zones often represent the convergence of two currents where one sinks beneath the other. Oil, whether in emulsion or solution, or attached to sinking particles, could be refluxed or carried downward by these sinking waters into the lower layer that flows inland. The situation could be similar in the highly turbulent and constricted passages of the San Juan Islands.

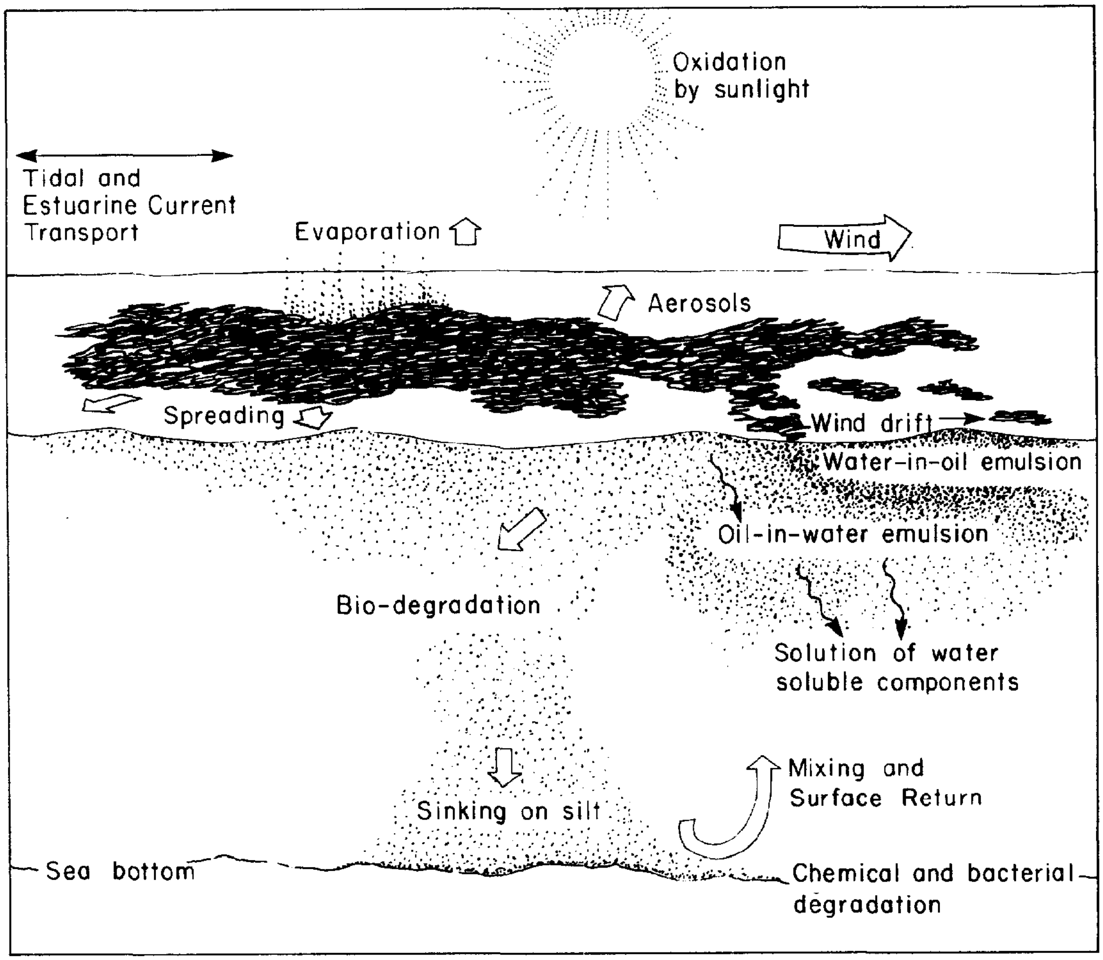
Microbial degradation of crude oil on water or beaches is likely to be slow due to limited nutrient availability and low temperatures.

Certain microorganisms, notably many bacteria, and to a lesser extent, fungi and yeasts, have the ability to utilize complex hydrocarbons as sources of energy (or food), and, thus, provide a biological system for the natural clean-up of spilled oil. Studies of this process were conducted for two years with water and beach sediment samples collected from more than 40 sites. All tests were performed in laboratory conditions simulating those of the study area.

No chemical change in crude oil attributable to microbiological processes took place over a 28-day period under "natural conditions." A minor amount of degradation took place when the studies were extended to three months. When nutrients (nitrogen, phosphorus) were added to ,the water samples, maximum rates of oil degradation of 50.5, 13.5, 37.7, and 14.6 mg of oil removed per liter of water per day were recorded at 8° Centigrade for samples taken from Fidalgo Bay, Ediz Hook, Peabody Creek (near Port Angeles), and Dungeness Spit, respectively. Negligible activity was observed in samples taken from Point Partridge. Thus, as indicated by the values above, oil degradation potential, particularly in the Port Angeles



Relative hydrocarbon levels in intertidal sediment (hatched bars) and mussels (clear bars) collected at 23 sites. *Data are based upon summed concentrations of 10 aromatic hydrocarbon concentrations. ND = none detected.



Major processes affecting the movement and fate of oil in the marine environment.

area, was highest in areas subjected to chronic inputs of oil or other hydrocarbons and lowest in areas distant from these inputs.

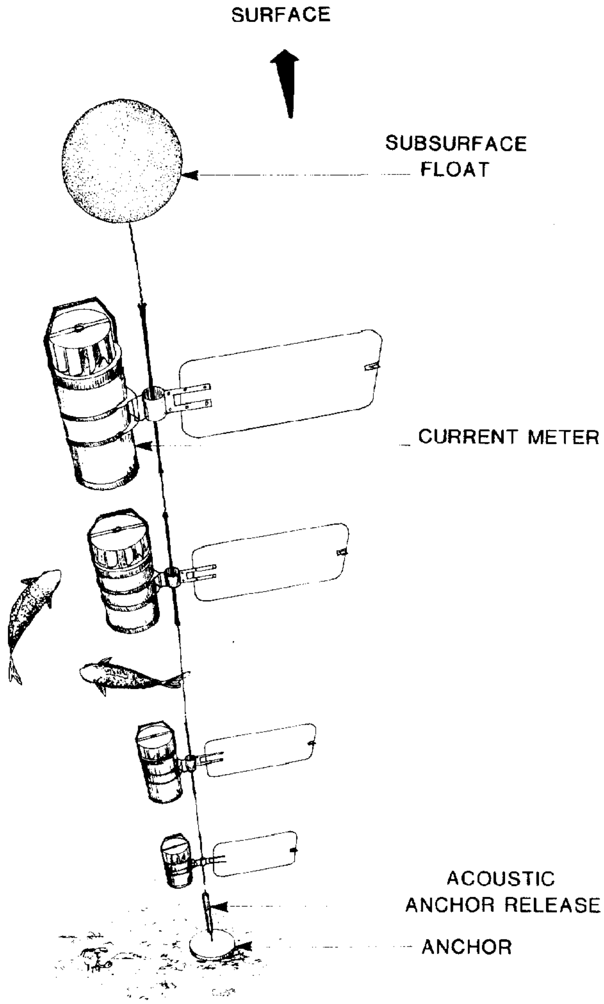
A lag time of 20 to 30 days usually was observed between the time nutrient-enriched water or beach samples were exposed to oil and the time when degradation took place. This time lag was smallest in areas where chronic hydrocarbon inputs were greatest. About one-third of the weight of crude oil was removed by mechanical weathering, another one-third by microbial degradation, leaving a residue of about one-third the original weight of oil.

The overall implication of these data is that over the short time period of an oil spill, say one week, microbial degradation would not be particularly important in changing the amount or composition of spilled oil under "natural conditions". Over a longer period of time, however, ultimate removal of oil would be facilitated by this process.

Sorption of oil by suspended particulate matter is unlikely to play a major role in removing oil from the open waters of the Strait of Juan de Fuca.

As used here, the term "sorption" refers to the ability of suspended particles to either attract and hold petroleum hydrocarbons to the surface of the particles or to attract and incorporate them into the particles. Suspended particulate material, such as particles of silt, clay, and organic debris, carried to the marine waters by local rivers has the property of taking up or accumulating oil. Laboratory tests with suspended material from the Fraser River and Skagit River, the two major sources of freshwater and sediment to the Strait, showed that these particles can accommodate up to their own weight in oil. As particles increasingly sorb more oil, they increase in density and can eventually sink to the bottom, thus providing an effective means of removing spilled oil from the surface and near surface layers of the water column.

During an oil spill, this sorption/sedimentation process could be important in reducing the effects of oil upon surface-dwelling marine organisms such as plankton, juvenile fishes, and marine birds. However, this process would be effective only in areas where suspended particles were concentrated. The lowest concentrations of suspended particles encountered in



Typical subsurface current meter mooring.

the study areas were in the open water of the western and central Strait; the highest were near the river mouths and among the northern San Juan Islands north to the Fraser River.

Oil-laden particles, once removed from the water's surface, would tend to accumulate on the bottom, especially in protected, low-energy areas like embayments. It is possible, then, that oil could accumulate in the detritus and mud of these protected areas and subsequently become incorporated into the food webs that ultimately depend largely upon consumption of this detritus. (The role of detritus in food webs is discussed in more detail later in this report.)

Overall, then, during an oil spill, oil sorption and sedimentation would likely be relatively unimportant in deep open waters due to the lack of suspended matter. However, it would likely be very important in nearshore areas or river plumes where suspended matter is most concentrated and very efficient at attracting and sorbing oil.

Complex water circulation in the Strait of Juan de Fuca and northern Puget Sound region makes it difficult to accurately predict the movement of spilled oil.

Water currents, tides, and winds are the most important factors to consider in predicting the fate of an oil spill in the region. For three years, Project researchers studied water circulation throughout the length of the Strait of Juan de Fuca to determine the physical oceanographic processes that would disperse and transport a potential oil spill. Tides, currents, water temperature, and salinity were recorded at numerous locations and depths, along with weather data such as wind, sea level pressure, and air temperature. Standard oceanographic recording instruments such as current meters, water bottles, thermometers, and conductivity-temperature-depth recorders were used to obtain a large number of measurements. Measurements taken by these instruments were augmented by satellite infrared imagery to detect and track the movement of water parcels and by a high-frequency radar system developed by NOAA, called CODAR, that can transmit signals from shore to instantaneously measure and map the surface currents over an extensive area. Specially designed objects that drift with the currents, called "drift sheets" and "drift cards", were put onto the water surface in great numbers to supplement the detailed current observation program and to aid in determining trajectories of a potential oil spill and the coastal resources that might be impacted.

Water flow in the Strait of Juan de Fuca may be characterized as a two-layered estuarine-type circulation. This two-layered system consists of a well-developed fresher and less dense upper layer directed seaward at about 0.4-0.8 knot with denser, more saline ocean water directed landward at around 0.2 knot in the lower layer. The fresher upper layer reflects the discharge primarily from the Fraser and Skagit Rivers and from lesser rivers and streams in the Puget Sound region. In the absence of other physical forces, this estuarine circulation might support the commonly held belief that surface-trapped material would be rapidly carried out to sea. However, other forces are superimposed on this estuarine circulation and greatly complicate the picture.

The daily ebbing and flooding of the tide and their associated tidal currents add another dimension to the circulation pattern. Spring tide heights range from about 10-13 feet and tidal currents of 1½-2½ knots are common, and often exceed 6 knots in restricted passages. Tidal ebb and flow currents are responsible for the back-and-forth motion of the water and contribute to the formation of eddies on the lee side of promontories, such as Dungeness Spit, and the formation of convergence fronts where opposing waters meet, mix, and oftentimes, sink. Mean flow in the eastern part, or basin, is further complicated by topography and the three major channels which empty into the basin, the result being a weak clockwise circulation pattern in this area. With the exception of a net eastward flow in the nearshore waters between

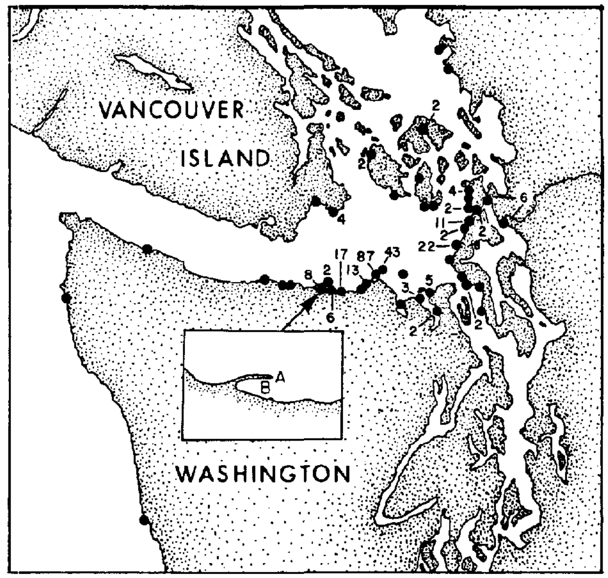
Ediz Hook and Dungeness Spit, little else is known about water transport along the shores of the Strait. Other forces, not entirely understood, tend to direct the flow southward across channel at the surface, or perpendicular to the axis of the Strait, especially in the western Strait.

Regional wind patterns as well as localized winds over the water also complicate the circulation, but the magnitude of their contribution is uncertain. Intrusions of Pacific Ocean water generated by coastal winds have been observed year-round in the Strait. These intrusions of coastal water have the effect of reversing the normal estuarine out-strait surface flow and have been observed as far east as Dungeness Spit.

Much has been learned about the general circulation patterns in the Strait of Juan de Fuca and the physical processes involved. However, the answer to the question, "Where would an oil spill go?" is dependent upon the location of the spill and the direct or indirect influences of many of the variables discussed previously, that is, tides, winds, currents, etc. The accuracy of the answer, or our ability to predict the trajectory of an oil spill, is closely tied to the rate the variables change and the length of prediction desired. For example, consider an oil spill in mid-channel directly north of Port Angeles. In the absence of any wind, it is expected that the oil would be carried by the estuarine out-strait surface flow toward the Pacific Ocean. An out-strait blowing wind would accelerate the movement and a slight in-strait wind would retard the speed of transport. In either case, the wind would impart some new motions to the trajectory of oil. An intrusion of Pacific Ocean surface water into the Strait during the oil's trek to the ocean would reverse this flow and could carry the oil into the eastern part of the Strait. Regardless of the direction of oil transport, lateral spreading of oil would occur, possibly resulting in fouling of beaches along the spill trajectory. Now, consider the same oil spill, but under different conditions. With strong, persistent westerly winds and a flooding tide, the oil would be expected to move eastward into the eastern basin. There it would be carried and dispersed by the complex circulation in this area. On a day-to-day basis with updated weather information the trajectory of oil on water can be predicted with a fair degree of accuracy, assuming that the kind and location of the spill are known, along with the stage of the tide and direction and speed of the winds. Beyond the day-to-day forecasts, additional information is needed before accurate long-range predictions can be made about the physical fate of an oil spill.

Oil spilled in Port Angeles Harbor and nearby surface water would most likely reach Dungeness Spit and points farther to the east.

Port Angeles Harbor, located behind Ediz Hook in the Strait of Juan de Fuca, is under serious consideration as a crude oil marine terminal. It is proposed that tankers in the harbor transfer crude oil through submarine pipelines to storage facilities located ashore at Green Point. From Green Point, a 42-inch diameter pipeline is proposed that would carry the crude eastward to a terminus in Clearbrook, Minnesota.



Recovery positions of drift cards released during April 24-30, 1978, in vicinity of Port Angeles (see insert for release sites). Numbered dots indicate multiple recoveries.

Project researchers conducted a number of studies in order to determine the surface path of a potential oil spill in Port Angeles and nearby approaches and the shoreline areas that might be impacted. Surface drift sheets and current drogues which move with the water surface and subsurface layers, respectively, were released and tracked by boat and aircraft. Numerous drift cards were released and their onshore recovery times and locations reported by card finders. All available historical oceanographic data from 1932-1979 were collected, analyzed, and synthesized. The data included observations of tides, currents, winds, freshwater runoff, water properties, and the transport of two previous oil spills, suspended sediment, and pulp mill effluent. A hydraulic tide model was constructed to provide the continuity in time and space necessary for the adequate synthesis of the data. The model compared favorably with actually observed water movements.

Results of the studies suggest that the surface water layers in the harbor may have a residence period of several days to a week. The residence time for water at depth is unknown because of insufficient data. The data would seem to indicate that an oil spill in the harbor would remain in the harbor long enough to be cleaned up or prevented from escaping. However, the location and size of a spill in the harbor as well as the tide cycle, wind speed and direction during and after a spill could alter considerably the residence time for a surface pollutant. For example, of 100 drift cards released in the entrance to Port Angeles Harbor off Ediz Hook on April

27, 1978, 61 cards were recovered the next day on Dungeness Spit. This suggests that a very short residence time is possible.

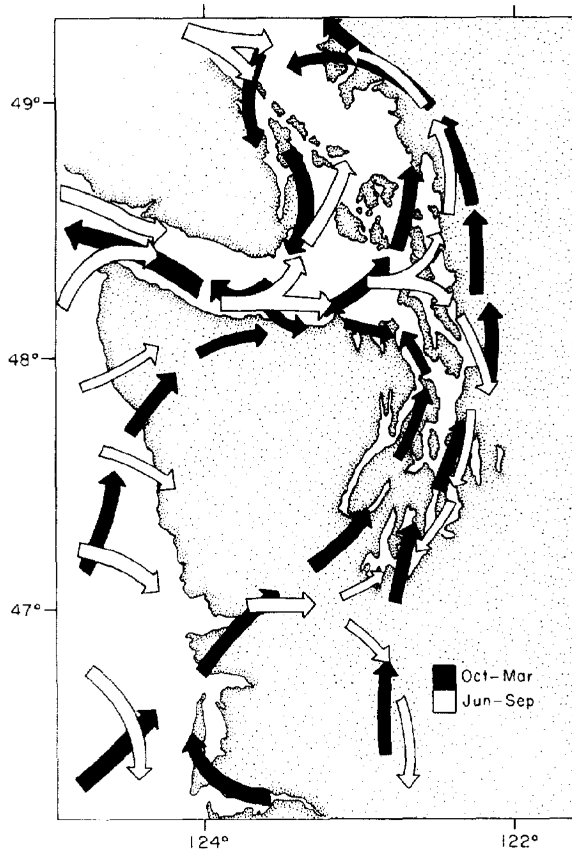
Once outside the harbor, both the predominant westerly winds at Port Angeles and the eastward nearshore water surface transport between Ediz Hook and Dungeness Spit would tend to move a surface pollutant toward Dungeness Spit and eastward. This transport and dispersion were illustrated by the behavior of a previous oil spill, suspended sediment from local rivers, creeks, and eroding cliffs; effluent from a Port Angeles pulp and paper mill; drift sheets and drift cards released in and near the harbor; and dye released in the hydraulic tide model. Concentrations and the effects of pulp mill effluent released in Port Angeles Harbor have been observed as far east as Dungeness Spit. Model studies indicate that surface contaminants could reach behind Dungeness Spit and to the mouths of Sequim and Discovery Bays. Recoveries onshore of drift sheets and drift cards show similar transport and dispersion from Port Angeles Harbor, with drift cards reaching a wide area including Sequim and Discovery Bays, Puget Sound, Whidbey Basin, and the Strait of Georgia.

Winds could be important in the transport of a surface and near-surface waterborne contaminant such as oil.

The effect of the winds on the water is to produce surface currents by transferring energy from the winds to the waves and then into surface currents. A rough rule of thumb for this effect is that wind currents usually move at approximately 3 percent of the wind speed. Theoretically, a 20-knot wind blowing persistently in a nearly constant direction for a half day or more should generate a surface current of about 0.6 knot directed approximately 10 degrees to the right of the wind. These wind-generated surface currents will either strengthen or weaken other currents in the Strait, such as tidal and estuarine currents. Since the estuarine flow is about 0.4 to 0.8 knot, the movement of floating oil may be controlled by winds under some circumstances.

Because of the funneling effect of the mountain ranges that border the Strait of Juan de Fuca, winds in the western portion of the Strait tend to flow either up-strait or out-strait. Generally, winds are westerly during the summer months (June-September) and easterly during the winter season (October-May). East of Race Rocks in the eastern portion of the Strait, winds are more confused and complicated during both seasons. Winter weather is usually dominated by low pressure systems, or cyclonic storms, that migrate across or north of the region which temporarily redirect the winds in the Strait from easterlies to westerlies. Also, in winter, high pressure systems located north of the region can direct cold continental air southward to alter the wind patterns.

Besides the local seasonal wind-driven currents, there are other wind patterns that could have a significant effect in moving surface pollutants about. Seldom do winds in the western Strait parallel the



Prevailing surface winds.

shoreline. Under some circumstances, the cross-channel component of the local winds could be sufficient to move pollutants shoreward to the north or south. Coastal storms also can dramatically affect the circulation in the entire Strait of Juan de Fuca. These storms, associated with persistently strong south-southwesterly coastal winds can cause reversals in the normal upper layer flow in the Strait. When these winds persist for three or more days, the sea level surface rises at the entrance to the Strait. This piling-up of coastal water results in an in-strait propagation of coastal water and reversal of normal out-strait flow in the upper layer. Reversals have been observed both during the winter and summer for periods up to 10 days with speeds of over 1 knot off Neah Bay with Pacific Ocean water propagating eastward off Dungeness Spit. The duration and extent of reversals vary with the strength and persistence of the southwesterly winds off the coast and can occur in any season.

The potential for an oil spill beaching increases with eastward distance into the Strait of Juan de Fuca.

Surface waters of the Strait of Juan de Fuca mostly undergo a net seaward transport of around 0.4 to 0.8

Black and white photograph of satellite infrared image of Puget Sound taken September 13, 1979, showing intrusion of warmer (darker) Pacific Ocean water into the Strait of Juan de Fuca. Shorelines were darkened for clarity.

knot. This observation implies that a contaminant trapped in the surface layer would be rapidly carried out the Strait to the Pacific Ocean before touching shore or beaching. It must be kept in mind that net transport is the result or sum of numerous motions of a particle or parcel of water. Net transport does not single out the vagaries of motions caused by the tides, winds, and other current-driving forces and, therefore, does not represent the actual path of a parcel of water. It is highly likely that a surface pollutant such as oil would travel a rather circuitous route, especially over many tidal cycles and varying wind conditions before it reaches some final destination. Oil may come ashore and subsequently be relaunched repeatedly.

The 80-mile-long Strait of Juan de Fuca has been shown to be a highly energetic and complex system, the complexity dramatically increasing inward from the Pacific Ocean. Superimposed on the estuarine circulation which eventually transports surface waters out to sea are the water motions associated with the tides and winds and the reversals that propagate up the Strait. Because of these and the complex patterns of eddies, fronts, and shore-directed current components, the potential for beaching an oil spill greatly increases eastward into this 80-mile-long waterway.

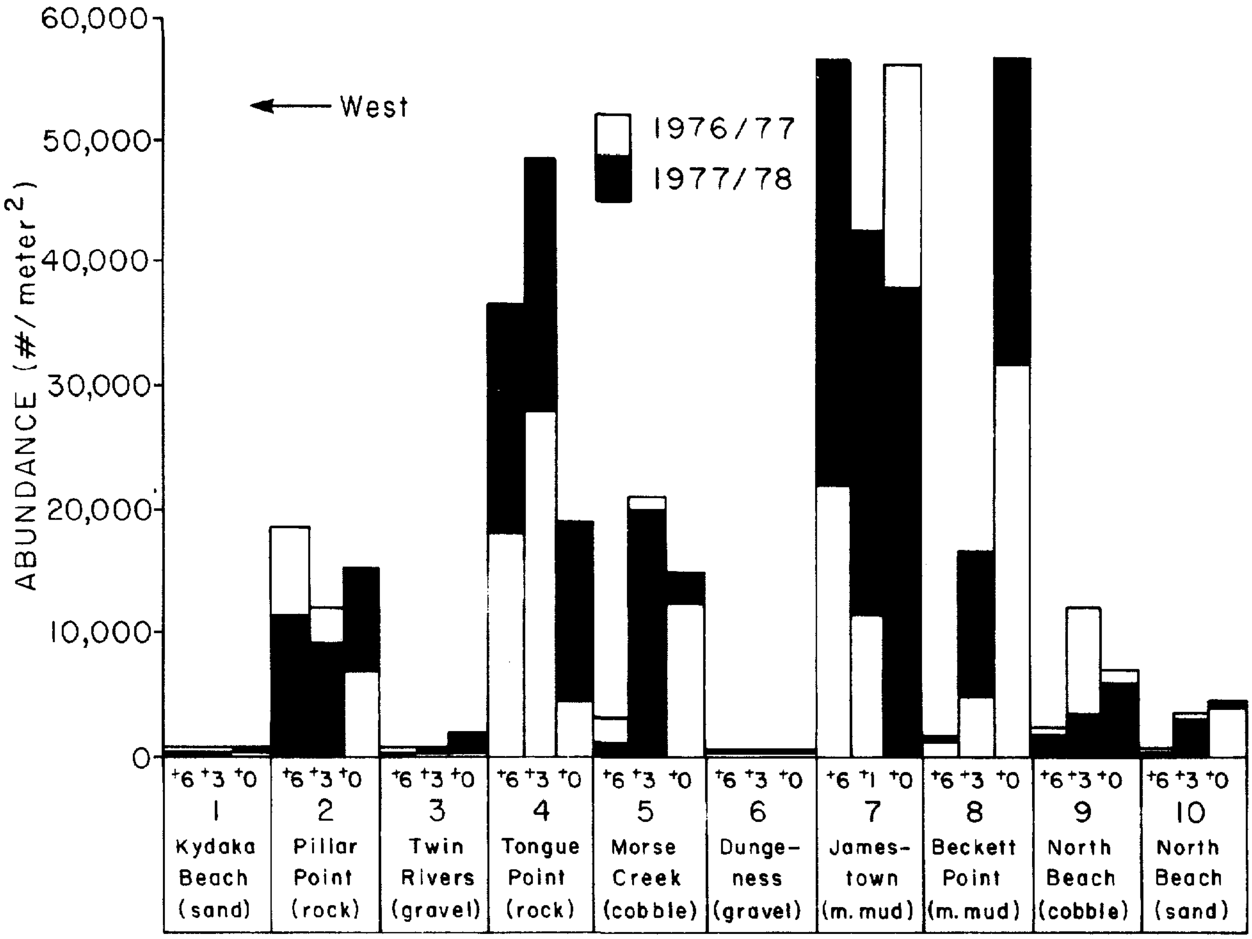
Areas of the shoreline with rock, cobble, or protected mixed-mud habitats are most important for intertidal organisms.

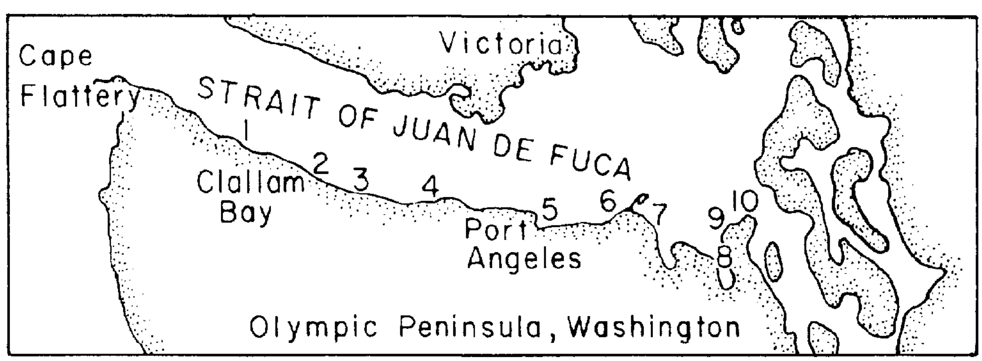
The amounts and kinds of organisms, such as barnacles, clams, and mussels, that inhabit the intertidal zone vary from habitat type to habitat type. The intertidal zone is that part of the shoreline that is repeatedly exposed at low tide and submerged at high tide. For two years, each major habitat type (for example, rock, sand, mud) that occurs in the study area was sampled at representative locations seasonally. Deeper water (5 and 10 meters) organisms, called subtidal benthos, were also sampled at the same locations. They live within the bottom sediments or attached to the bottom and include clams, worms, shrimp, and kelps. Ten locations were studied along the Strait of Juan de Fuca. Using similar methods, the Washington Department of Ecology sampled numerous locations in the San Juan Islands and northern Puget Sound.

The biota that inhabit the intertidal zone were most abundant in mixed-mud habitat samples collected at Jamestown east of Dungeness; a maximum of over 50,000 organisms were found per square meter of beach. Abundance was usually highest at the lower tidal elevations. Samples taken at rock and cobble locations also showed high abundance. Organism abundance was often lowest at sand and gravel beaches.

The total numbers of species found was highest (over 160 species) at locations with rocky habitat followed by those with cobble, mixed-mud, sand and gravel habitats. Because many of the organisms associated with rock are large and/or have thick shells, the total weight of biota was highest (as much as 11,000 grams per square meter) at rocky locations.

The biota found along the Strait were more diverse and dense, especially on rock, than those found in the San Juan Islands and roughly equivalent to those found in the Anacortes-Bellingham area. Some species found in the western part of the Strait were also known to occur on the outer coast but do not occur inland. Very few organisms found on rock were found in mixed-mud or other unconsolidated beaches. Cobble beaches had a mixture of species from both rock and unconsolidated habitat types.





Average abundance of intertidal organisms collected at three tidal elevations (+6, +3, +0 feet) at 10 sites.

Organism abundance, numbers of species, and total weight were usually highest in spring and summer. The kinds of species varied seasonally. Small-scale variations in habitat type, exposure to waves, slope of the shore, water quality, and other environmental factors also contributed to considerable variations in the kinds and abundance of biota with time.

Subtidal benthic organisms were somewhat more abundant in areas with mixed-mud habitats than in other areas. Abundance was lowest in areas with gravel. Numbers of species were roughly equivalent in all areas, showing a small increase from the western end of the Strait to the east. The weight of these organisms also increased eastward along the Strait, except where a highly productive rocky location in the western Strait was sampled.

Small detritus-consuming animals are most concentrated in protected nearshore habitats, are very sensitive to the effects of oil, and are the major prey group for many other animals.

Studies of the feeding habits of many animals found in the area and examination of available information have shown that food webs based upon detritus-consumpton are the most important of the food webs occurring in nearshore habitats. Detritus is formed by the decomposition of organic plant and animal material. It accumulates primarily in protected embayments, mudflats, and eelgrass beds, though it may originate elsewhere, such as at kelp beds and marshes.

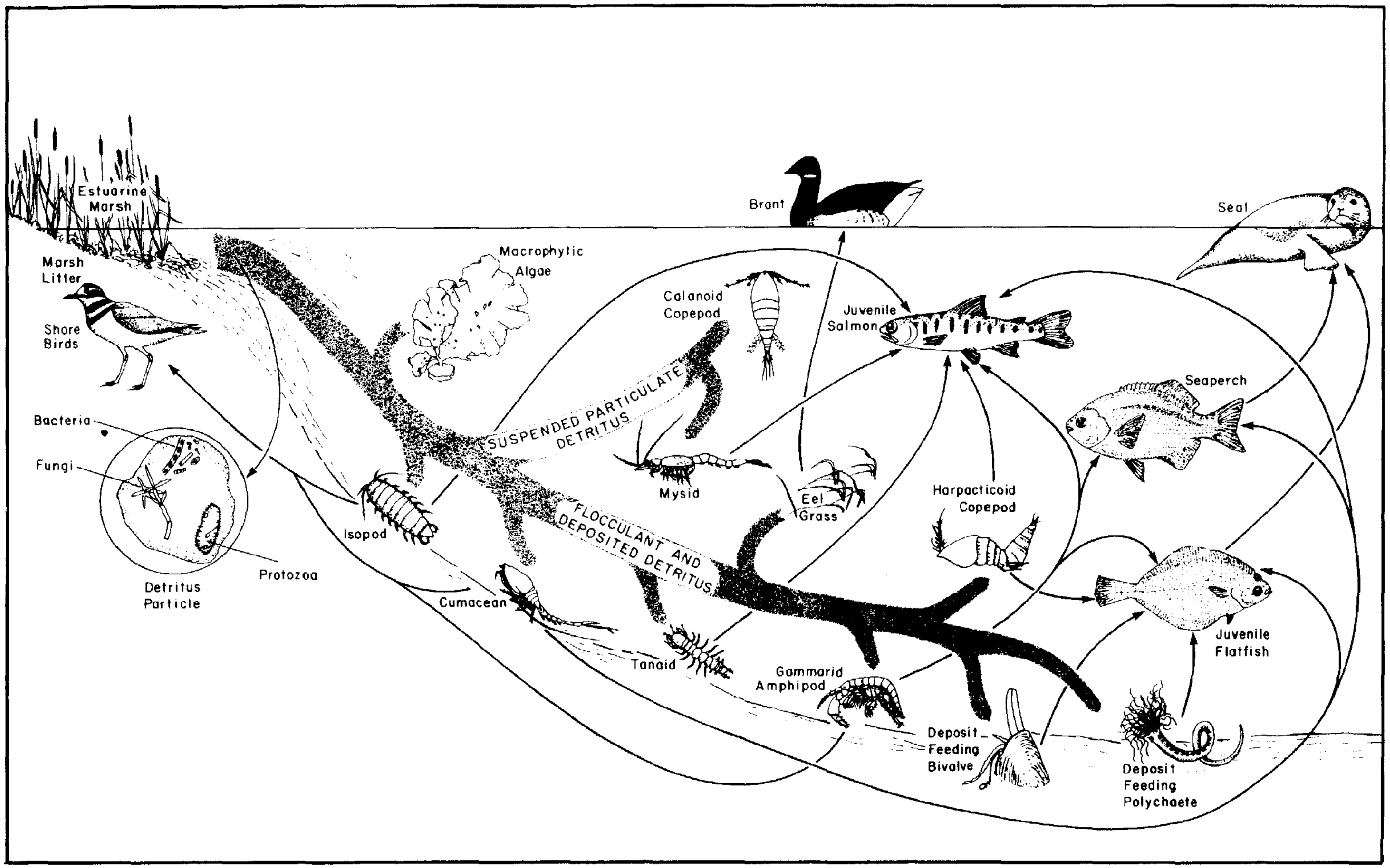
Small crustaceans, such as copepods, amphipods, and other shrimp-like organisms, and to a lesser extent, other animal groups, living near or on the bottom are called epibenthic zooplankton. They are the initial consumers of detritus. Samples taken along the Strait showed that these animals were up to 10 times more concentrated in the protected eelgrass beds southeast of Dungeness Spit than elsewhere. Many of the bottom fishes that inhabit nearshore waters of the Strait are highly dependent upon epibenthic zooplankton; thus, these fishes are very abundant in protected nearshore habitats. During their migration to the Pacific Ocean, juvenile salmon from all the rivers in the Puget Sound region pass through the Strait and feed almost exclusively upon the epibenthic zooplankton in the shallow water along the shoreline. The majority of the marine bird species in the area feed upon small fish and bottom invertebrates and the majority occur in shallow nearshore waters, salt marshes, and mudflats. Brant feed upon eelgrass. Densities and total numbers of marine birds were highest year-round in protected embayments and mudflats such as those that occur southeast of Dungeness Spit. The most common marine mammal in the area, the harbor seal, also eats bottom fishes and invertebrates, which, in turn, consume epibenthic zooplankton.

Circumstantial and experimental evidence indicate that detritus-based food webs are very sensitive to the effects of oil. Detritus tends to sorb oil droplets. It usually is most concentrated in protected areas where winds and water currents have little effect in diluting or dispersing oil or oil/detritus mixtures. The accumulation and incorporation of petroleum hydrocarbons into muddy and detrital sediments could result in prolonged recycling of persistent compounds through the food web. Since oil could remain bound to these sediments for years, repopulation could be very slow. New arrivals may be subjected to lingering oil pollution for many years. Many of the detritus-consuming crustaceans that are important members of the epibenthic zooplankton were found to be sensitive to the effects of oil (discussed below). Major repercussions to animals, such as juvenile salmon that are highly dependent upon epibenthic zooplankton, could occur in the event of the loss or contamination of these organisms during an oil spill.

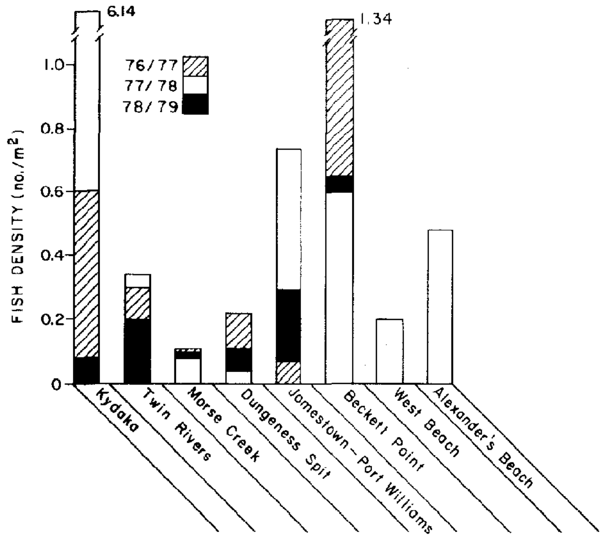
Areas of the shoreline with protected unconsolidated habitats are most important for many nearshore fishes.

Fish that live in the surf zone and nearshore waters were sampled at eight locations along the Strait seasonally for up to three years. Sampling was done with three methods. Trawl nets towed behind a boat were used to collect fishes that live in water about five meters deep, usually on the fringe of the kelp beds. Beach seines, another kind of net, were deployed by rowboat and pulled ashore by hand to sample fishes that live in the shallow water in or just outside the surf zone. Aquarium dip nets and similar devices were used to collect fishes that occupy tide pools or depressions under cobbles. The kinds and numbers of fish were determined and the stomach contents were examined to determine dietary habits. The same kinds of trawls and beach seines were also used by the Washington Department of Ecology in nearshore fish studies at about 15 locations in the San Juan Islands and northern Puget Sound. It is important to note that no studies were undertaken to characterize commerical fisheries. For example, adult salmon populations were not sampled, though juvenile salmon were recorded as a part of beach seine and trawl catches.

Numbers of species, total abundance, and weight of nearshore fish caught in beach seines were often greatest in samples collected in protected, mixed-mud habitats, particularly at Beckett Point in the mouth of Discovery Bay. Fish catches at exposed sand and gravel beaches (e.g., Morse Creek, Dungeness Spit, West Beach) in the Strait usually were low. However, infrequent capture of schooling fish such as smelt or herring sometimes resulted in unusually large catches at these sites. For example, a very large catch was made at Kydaka Beach in the summer of 1977. The rich fish fauna captured in beach seines at Beckett Point consisted mainly of flatfish, sculpins, perch, and cods. As many as 30 species were caught at Beckett Point per sampling period; whereas, rarely more than 20 species were caught elsewhere. Nearly 20 grams of fish per square meter of water were collected in individual samples at Beckett Point. Similar data collected in the San Juan Islands and northern Puget Sound confirm that protected mixed-mud habitats are highly important for shallow-water fish.



Simplified example of a detritus-based nearshore food web.



Average density of nearshore fish caught in beach seines during three years at eight sites.

The numbers and weight of fish caught in trawls were more variable than for beach seines due to the greater influence of schooling fish. Few trends in the data were apparent because of the high variability, though catches were usually greatest in spring and summer and lowest in winter. It is apparent from the data that most trawl-caught fish are relatively uniformly distributed along the shoreline of the Strait and are occasionally augmented by large schools of smelt and herring or the infrequent capture of a single large fish, such as a dogfish, which greatly influences the total weight of the collection. The Pacific herring was by far the most abundant species. Similar data collected in the San Juan Islands and northern Puget Sound confirmed that catches were usually greatest in spring or in summer. Sites sampled in the San Juan Islands had the fewest species; those in the eastern Strait had the most. Overall, fish abundance was highest along the Strait and total weight was highest in the Cherry Point/ Lummi Bay area.

Totals of 60 and 81 species were caught during the three years of study in trawl and beach seine collections, respectively. Many of the species found were larvae and juveniles, reflecting the extensive use of nearshore habitats as nursery areas for local species. The most prominent feeding habit was one that depended entirely upon epibenthic zooplankton, those small organisms that live in the water very near the bottom.

The sculpins were most common among the 26 species of tidepool fishes found in the study. The numbers of species found at each site increased slightly from the east end of the Strait to the west, possibly in response to increasing kinds of habitat types available. Many of the tidepool fishes were adults. Seasonal trends in abundance were not apparant. Most tidepool fishes were found to prey upon small crustaceans; many of them feed exclusively on these animals.

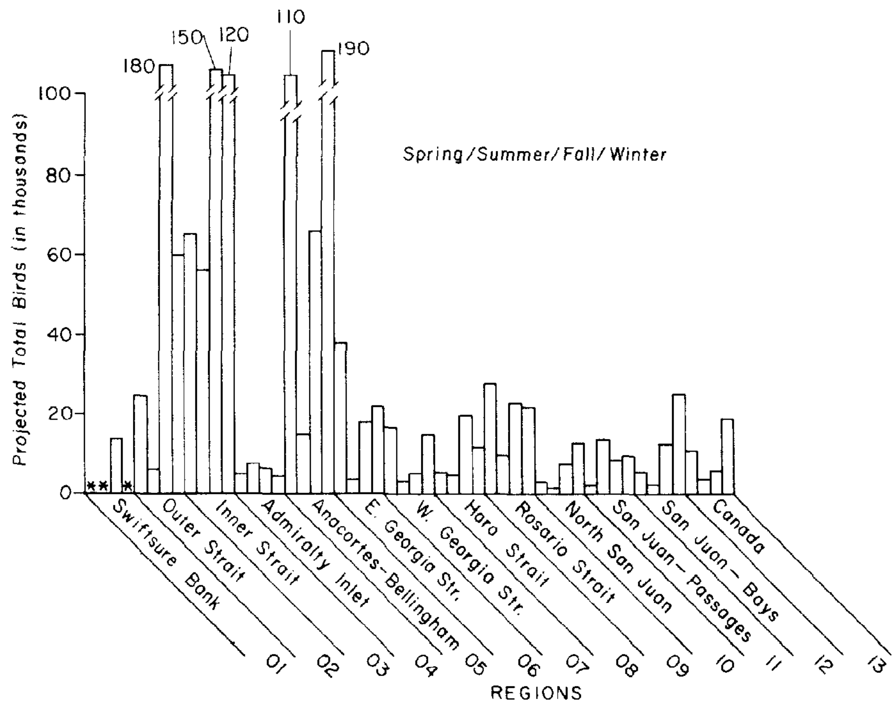
The Strait of Juan de Fuca and northern Puget Sound regions support a large and varied population of marine birds.

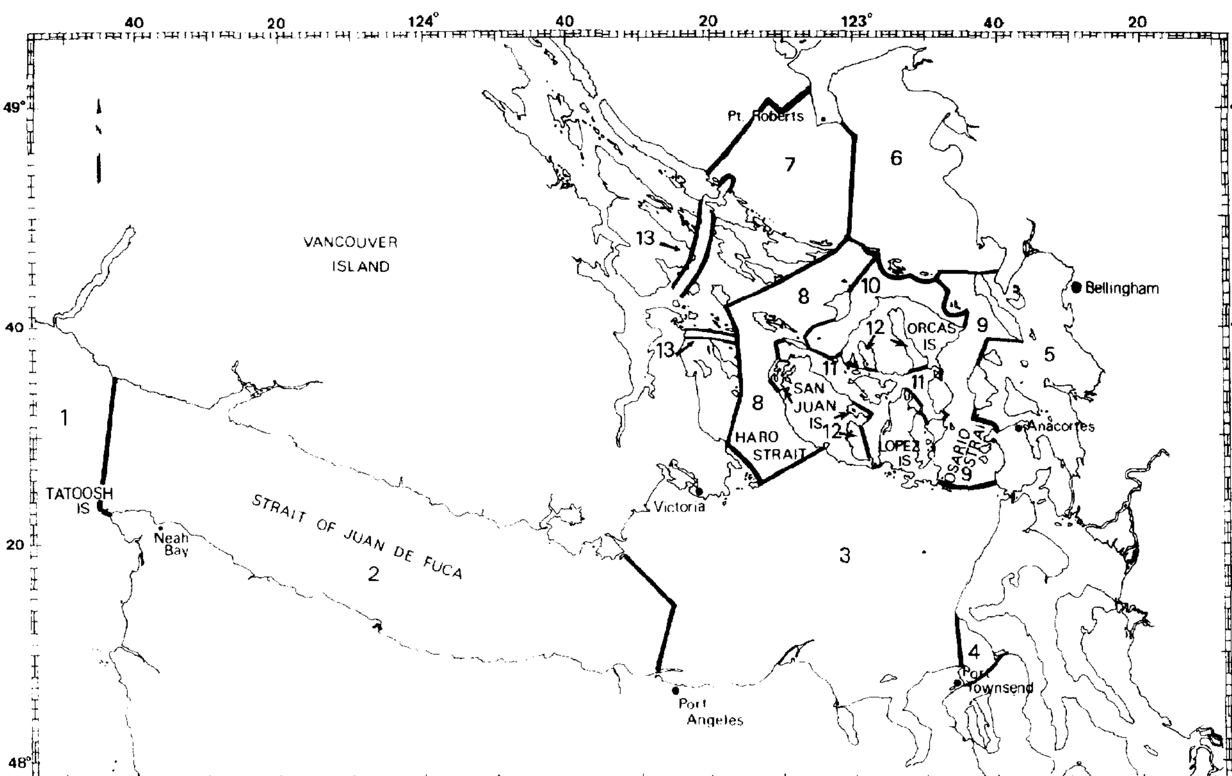
Marine bird surveys were performed at least monthly from planes, boats, ferries, and on land throughout the study area for two years to determine areas of relative importance. The study area was broken up into 13 major regions, each of which encompassed subregions of various sizes. Regions found to be important for marine birds were the offshore waters of the outer Strait of Juan de Fuca (a part of Region 02) in the fall and winter; offshore waters and the Jamestown shore of the inner Strait (parts of Region 03); the Padilla Bay/Samish Bay/ Bellingham Bay complex (parts of Region 05); and the shore of Lummi Bay, Cherry Point, Boundary Bay, and offshore waters in the Eastern Georgia Strait region (parts of Region 06). In most regions, bird densities were greatest in the fall and winter when migratory birds were present. Many of the passages and channels among the San Juan Islands had relatively few birds, though large numbers occasionally occurred where tidal currents were strong.

About 130 species were observed. Many of the species known to be sensitive to the effects of spilled oil were found in large numbers in the protected bays of the inner Strait and Anacortes-Bellingham areas. Many species of loons, grebes, cormorants, and alcids were seen in deep water; shearwaters, sandpipers, ducks, geese, herons, and plovers were seen in shallow waters or on beaches. Gulls were seen throughout the area.

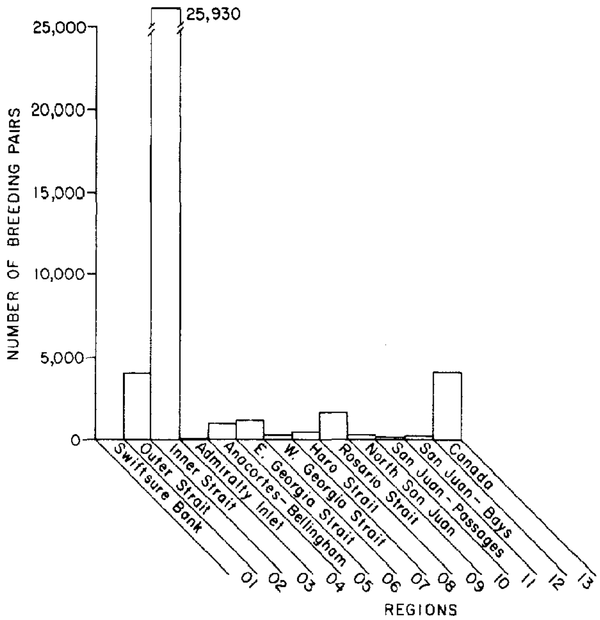
A projected estimate of 240,000 Common Murres were observed in the offshore waters of the outer Strait. A projected total of up to 69,000 birds, mainly Common Murres, were found in the offshore waters of the inner Strait. The Jamestown subregion contained up to 28,000 birds, mostly ducks, geese, gulls, and shorebirds. The Padilla Bay, Samish Bay, and Bellingham Bay subregions, together, may account for over 80 percent of the birds in the study area in the spring. As many as 90,000 birds, including migratory waterfowl, grebes, and shorebirds, were estimated to occur in Padilla Bay in the winter. Similar total counts of birds were estimated for Boundary Bay where scoters, other ducks, geese, and shorebirds were abundant. Though these studies did not include the area east of Whidbey Island, there is evidence that as many as 150,000 birds may occur there during the winter at any one time.

Approximately 39,000 pairs of breeding birds were counted in the study area. Rhinoceros Auklets (18,000 pairs) and Glaucous-winged Gulls (14,000 pairs) were most common. Nesting cormorants, storm-petrels, and alcids were also seen. A total of about 22,000 pairs were observed at Protection Island in the inner Strait region (Region 03), by far the most important breeding colony. About 17,000 of the pairs of birds on Protection Island were Rhinoceros Auklets. Other notable breeding colonies were found on Tatoosh Island in the outer

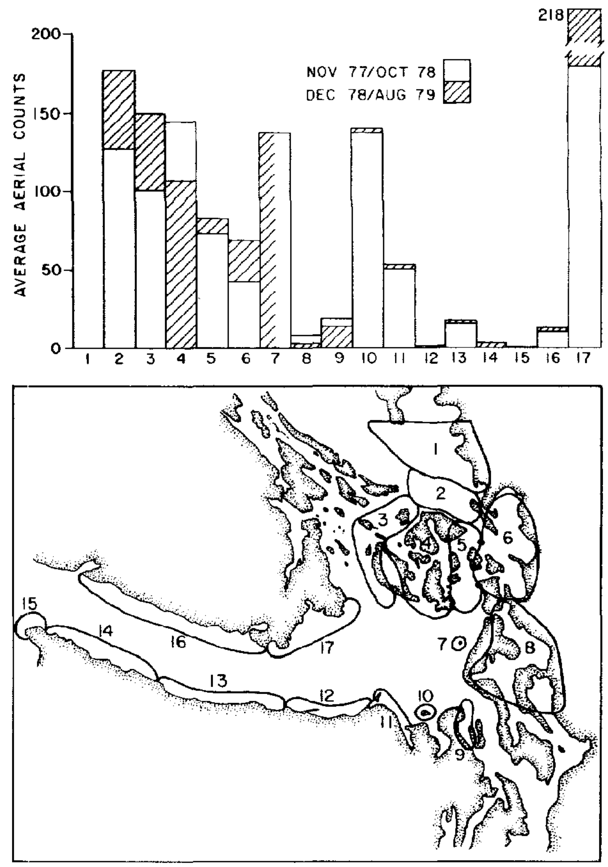




Regional projected total counts for all marine birds for each season (average of 1978 and 1979 observations). *indicates no observations made.



Regional totals of pairs of breeding marine birds (average of 1978 and 1979 data).



Average total counts of harbor seals observed in 17 regions in 1977-1978 and 1978-1979.

Strait (02), on scattered rocks and islands thoughout northern Puget Sound and the San Juan Islands (05, 06, 08, 10), along northern Rosario Strait (09), and on Mandarte Island in Canadian waters (13).

The area found to be most important to marine mammals is the eastern Strait of Juan de Fuca.

Twenty-one species of marine mammals exist throughout the area, and they tend to congregate at certain isolated locations. Places of importance to these species offer food and protection, and, in the cases of seals and sea lions, provide areas to haul out onto the shore for resting, escape from predators, and rearing of young. Generally, the waters and shorelines of the eastern Strait were most important for the marine mammals that were censused.

Field surveys by boat, plane, and beach walks were performed at least monthly for two years. Since harbor seals are by far the most abundant species in the area, their abundance and distribution was emphasized in the studies. The study area was broken down into 17 standardized regions for reporting survey results, especially for harbor seals.

Regions 2, 3, 4, 7, 10, and 17 had the highest average counts of seals. These regions correspond with the northern San Juan Islands, Haro Strait, interior San Juan Islands, Smith-Minor Islands, Protection Island, and the Race Rocks area of Vancouver Island. A peak count of over 200 harbor seals was made in the area at one time. Four islands (Smith-Minor, Protection, Chain, and Race Rocks) and four bays (Boundary, Dungeness, Samish, and Padilla) were most important for pupping activity.

Vulnerability of seals to oil pollution and disturbance is highest in spring and summer during pupping activities. Pups are less able to avoid humans and predators than adults and can be adversely affected during suckling by coming into contact with oil trapped in the mother's fur.

The cetaceans (whales, dolphins, and porpoises) were found throughout the area, but large numbers most often occurred in the eastern Strait of Juan de Fuca. Killer whales, numbering at least 80 animals in the area, are the most common cetaceans. Their feeding habits often take them through the eastern Strait of Juan de Fuca. Some species of cetaceans (for example, humpback whales) occurred in the area historically but have not been seen there in recent years.

Nearly 300 sea lions may occur in the area at one time; peak counts occur in winter from October to May. They were most abundant at Race Rocks, near Vancouver Island and at Sucia Island in the northern San Juan Islands. A group of over 100 California sea lions was sighted on a grounded barge near Everett in April 1979, a highly unusual event since these animals had previously been reported to congregate mainly on Race Rocks. The enormous (about 2,000 kg) northern elephant seal exemplifies many of the marine mammals in the area in that they occur there infrequently as migrants or as occasional visitors.

The shoreline habitats most sensitive to oil and most difficult to clean up are sheltered marshes and sheltered tidal flats.

Because human resources and equipment to combat and clean up large oil spills are often limited, it becomes necessary to make choices, especially during a large spill, as to what areas must be protected. These choices can be based upon predetermined criteria that consider the known behavior of oil on each kind of shoreline; the known kinds and amounts of biota usually associated with each shoreline type; and the relative difficulty involved in cleaning up a spill on each type.

To satisfy this need for criteria, an Environmental Sensitivity Index was developed and applied to the area. The index rates each shoreline habitat type on a scale of 1 to 10. The most sensitive type, sheltered marshes, is a 10 and thus warrants first priority in oil spill responses involving protection and cleanup. The 10 categories and their ranks are:

1. Exposed rocky headlands
2. Wave-cut platforms
3. Pocket beaches along rocky exposed shores
4. Sand beaches
5. Mobile sand and gravel beaches
6. Stable sand and cobble beaches
7. Exposed tidal flats
8. Sheltered rocky shores
9. Sheltered tidal shores
10. Sheltered marshes

As the data on abundance of intertidal biota, fish, birds, and mammals discussed above indicate, the highest ranked habitats often support the most plant and animal life. The exposed sandy and gravel beaches, wave-cut platforms, and pocket beaches (usually gravel) support little marine life. These habitat types, as well as exposed rocky shores, are easily cleaned of oil by wave action and/or by humans in clean-up activities.

Once the index was established, the Strait of Juan de Fuca and northern Puget Sound were surveyed by boat, foot, and plane to determine the extent and distribution of each shoreline type. Critical biological populations were also noted. A series of large-scale and small-scale maps were prepared that show in color code the occurrence of each shoreline type and unique biological features. These maps are available for use during oil spills (see Products).

The four most sensitive habitat types (ranks 7-10) were found scattered throughout the entire area. Most of the western Strait has low-ranking shorelines, primarily exposed rock and sand or gravel beaches. The sheltered marshes at the mouths of the Pysht River and Salt Creek are exceptions. Highly sensitive areas in the eastern Strait include Dungeness Bay, the tidal flats at Jamestown, and the tidal flats at the heads of Sequim and Discovery Bays. East of Whidbey Island, sensitive areas are the tidal flats at Port Susan, Skagit Bay, Penn Cove, and Dugalla Bay. In the Anacortes-Bellingham area, the sensitive shorelines exist in Padilla Bay, Samish Bay, Fidalgo Bay, and northern Bellingham Bay. The sensitive areas in the southern Strait of Georgia are the tidal flats at Roberts Bank, in Boundary Bay, Semiahmoo Bay, Drayton Harbor, and Birch Bay. In the San Juan Islands, the protected rocky shores on Sucia, Orcas, Stuart, San Juan, Shaw, Lopez, Blakely, and Decatur Islands are sensitive along with isolated tidal flats and marshes in Westcott Bay, False Bay, Mud Bay, Fisherman Bay, and Buck Bay.

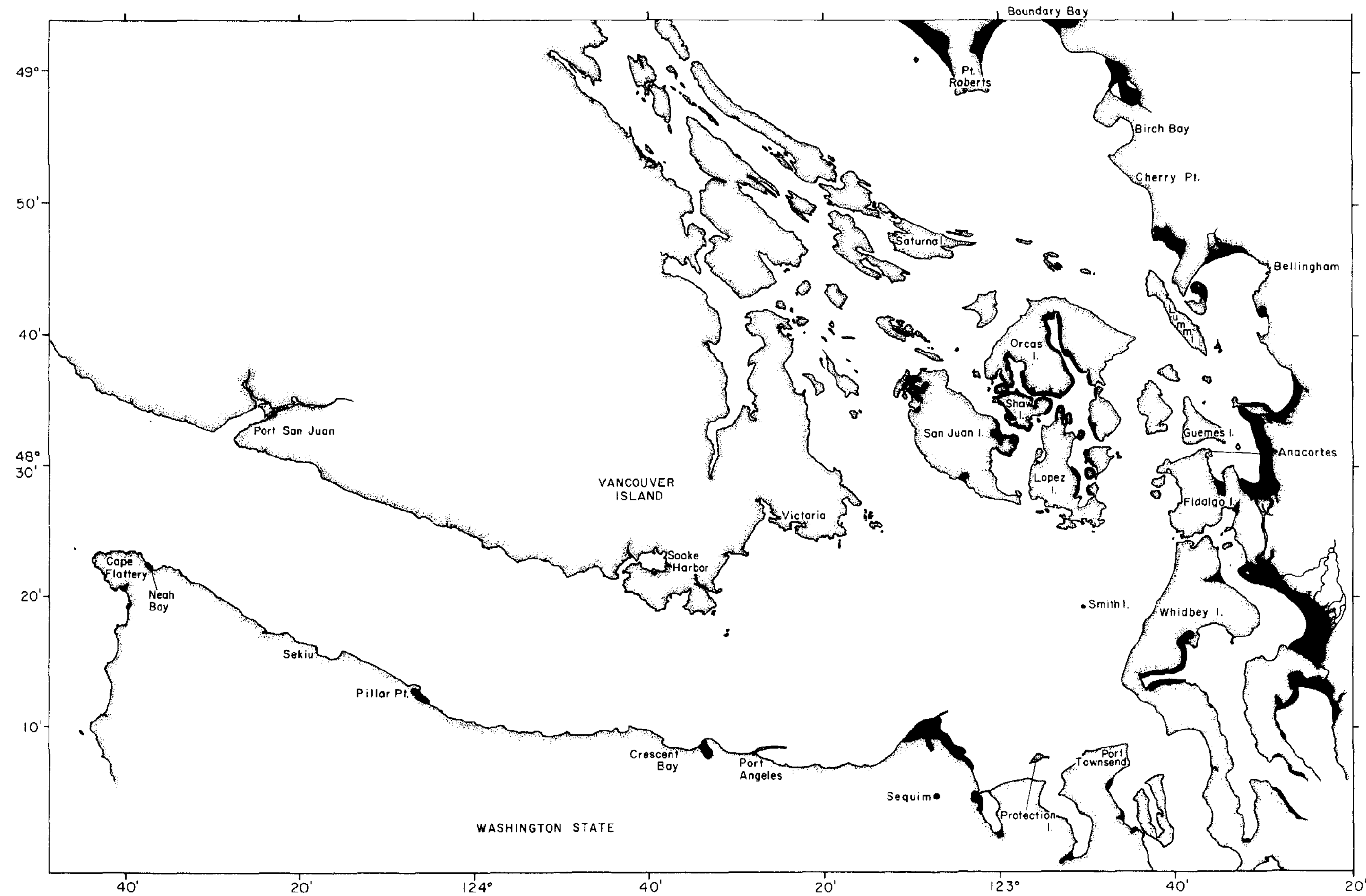
Critical biological areas were designated as such according to the occurrence of high concentrations of marine mammals (hauling out beaches), marine birds, spawning fish, and commercially important fish and shellfish. Primarily, these areas were found in the San Juan Islands, in the Padilla/Samish/Bellingham Bay complex, in the Tatoosh Island/Cape Flattery area, at Smith-Minor Islands, and in the Protection Island/Discovery Bay/Sequim Bay/Jamestown/Dungeness Bay area.

Biological communities living on rocks, in sand, and in mixed mud-gravel beaches are projected to recover from a single major oil spill in 3 to 13 months, 31 months, and 46 months, respectively.

The field surveys described above provided information on the relative richness of the intertidal biological communities of the region. However, no data existed on either the possible effects of oil on these communities or on the rates and processes of recovery of these communities following oiling. To address these concerns, a two-year series of experiments was conducted in the field at three locations in the eastern Strait of Juan de Fuca. The experiments involved many month-long, 3-month-long, and 15-month-long tests following single doses of crude oil. Beach materials were removed from several locations, repeatedly frozen and thawed to eliminate all living organisms, mixed thoroughly with Prudhoe Bay crude oil, and placed in permeable plastic boxes. The boxes were then partially buried in the original collection locations so that the top surface was flush with the beach surface. Tests were conducted in the mouth of Sequim Bay, in Discovery Bay, and on Protection Island. Concrete bricks were used in one set of tests to simulate a rocky substrate. All experiments were performed with untreated (no oil) controls.

The colonization of oil-treated and untreated substrates and the rates of loss of oil were measured by periodically subsampling the material in the boxes and on the bricks. The kinds and numbers of organisms in the untreated substrates at the end of the 15-month experiments were used as a definition of full recovery. When full recovery of oiled substrates did not occur within the period of the test, an estimate of recovery time was made, based upon projection of observed rates of loss of oil and rates of recovery.

Predicted full recovery time of a mixed mud-gravel habitat used for a commercial clam operation in Discovery Bay was 46 months, following initial oil



Occurrence of the four habitat types that rank 7 to 10 on the Environmental Sensitivity Index (darkly shaded areas).

treatment. For the sand habitats at Protection Island and the entrance to Sequim Bay, the full recovery time was predicted to be 31 months. Full recovery of bricks, used to simulate natural rock substrates, was predicted to be from 3 to 13 months in "best" and "worst" case situations, respectively.

Recovery in terms of numbers of species preceded that for numbers of individuals following oil treatment. For example, in one 15-month test, 69 percent of the species had returned after three months, while only 11 percent of the total individuals had returned relative to what was eventually found after 15 months. Recovery was slightly faster in summer-fall tests than in the spring-summer period. Recovery was faster at the -2 foot tidal elevation than at Mean Lower Low Water (0 elevation).

Oil was retained in the mixed-mud clam bed beach longer than in the sand beach. About 13 and 15 percent, respectively, of the initial oil concentration was lost from these two substrates in three months. Oil was retained longer at the upper tidal elevation than at the lower elevation. At the clam bed location, more oils was retained deep in the substrate than near the sediment-water interface. A high proportion (about 84 percent of the initial concentration) of oil was lost from the bricks in five days.

Among all the combinations of experimental conditions that were performed, 70 percent of the 56 biological parameters measured were significantly reduced by the oil treatments. Molluscs in the commercial clam bed, including the littleneck clam, and on the rock/brick habitat were found to be sensitive to oil treatment and slow to recover. Polychaetes (worms) and crustaceans were sensitive in sandy substrates. Detritus-consuming and plant-consuming animals were almost universally influenced by oil. Carnivores were less sensitive; suspension (filter) feeders the least sensitive.

Highly muddy substrates were not studied. However, there is evidence from large oil spills throughout the world that mudflats and marshes may require a decade or more to fully recover.

Huge numbers of planktonic organisms occur in the open water of the Strait, especially in the spring.

Though emphasis in the biological studies was placed upon nearshore and intertidal environments of the area, a study of the open water plankton of the Strait of Juan de Fuca was performed to determine what organisms may be at risk there to oil spills. Planktonic communities consist of drifting single-cell plants, copepods and other microscopic animals, and the eggs and larvae of numerous invertebrates and fish. These communities were sampled with a variety of nets, each designed to catch certain sizes of organisms at certain depths. Sampling was conducted at nine locations in the Strait 13 times over a two-year period.

Phytoplankton undergo a massive increase in numbers in the spring or early summer in response to increasing sunlight and temperatures. This phenomenon was noted in late June 1976. It was not observed in 1977, though it likely occurred. These phytoplankton organisms constitute the "grass" of the sea. Thus, the density of zooplankton that graze upon the phytoplankton also tended to increase markedly in June and July, often remaining high through August. These zooplankton are highly important prey for fish larvae, small open water fish such as herring, and juvenile fish such as pink salmon, which, in turn, are preyed upon by marine birds, large fish, and whales.

Fish eggs and larvae are known to be particularly sensitive to the effects of oil because many forms occur at or near the water's surface. Many species spawn only during a single short period of the year. The survival of one year's offspring could be jeopardized if an oil spill occurred when a year-class of a species was in the area of the spill. Samples taken with a net that passes through only the upper 10 or 15 centimeters of the water were taken specifically to collect the fish eggs and larvae at the surface.

The eggs and/or larvae of 49 kinds of fish were found in these surface samples. Fifteen were of known commercial value, including salmon, sole, smelt, greenling, herring, cod, and ling cod. The greatest numbers of species and individuals were seen in late winter and early spring. By counting the numbers of fish eggs in the volumes sampled and mathematically projecting them to the entire area of the Strait, the total population was estimated. An average of about 100 million eggs was estimated. A peak estimate of 500 million was made for April 1977. Estimated average and maximum total populations of fish larvae were made for April 1977. Estimated average and maximum total populations of fish larvae were 100 million and 650 million (during February 1977), respectively, for the upper water layer of the Strait.

Some unusual species of copepods appeared in some zooplankton samples. These species were known to usually occur in offshore Pacific Ocean water, and not in inland waters. When the incidences of these oceanic species were examined relative to oceanographic data, it became apparent that these species were entering the Strait during storm events. The eastward surface currents associated with these storms were determined through oceanographic observations described above. These oceanic copepods, thus, became indicative of unusual water currents otherwise measured with highly sophisticated electronic equipment.

Estimates of biological damage due to oil spills would be difficult to make from available data.

Statistical tests performed on the biological data showed that the kinds and numbers of organisms (birds, mammals, fish, invertebrates) were highly variable. Thus, if a spill were to occur that caused biological effects, our ability to estimate changes caused by oil in the composition and abundance of various communities would be limited.

Since some variability from place to place, season to season, and year to year was expected at the start of the project, biological studies were conducted for at least two years. The fish studies went for three years. Observations were made at numerous places and during each of the four seasons. However, the major objective of these studies was to characterize what biota occurred where and when, not necessarily to develop a data base against which oil-caused changes could be assessed.

Overall, upon examining the data available now, one could expect certain animals to usually occur at certain places and at certain times of the year, but could not predict very accurately the number that would be there at any specific time. For example, one could expect to find sea lions all winter at Race Rocks, but the number of them may vary from 35 to nearly 400. An average of about 140 harbor seals usually occur at Protection Island year-round, but the number at any time may range from 0 to over 200. The distribution of nesting birds appears to be relatively consistent from year to year, but migratory birds vary greatly at many places from one year to the next. The same species of fish, the Pacific herring, was always most common in trawl net catches. However, due to large variability in abundance, it was calculated that a 95 percent decrease in abundance or biomass of trawl net catches would be necessary to be statistically detectable. That is, if an average of 100 fish were known to occur at a certain location in a specific season and if a spill occurred there, a total catch of fewer than five fish would be necessary to conclude that an actual change in abundance had actually taken place.

The intertidal and shallow subtidal invertebrate data proved to be highly variable. Community composition varied considerably from place to place as expected. In addition, species and abundance for any single habitat type varied with tidal elevation, exposure to waves, seasons and years. Though absolute estimates of oil-caused changes in abundance of all species for all habitat types are probably impossible, the presence or absence of some species or groups of species can be estimated reliably, especially in well-defined, protected intertidal habitats.

A SYNOPSIS

This research project, "An Environmental Assessment of Northern Puget Sound and the Strait of Juan de Fuca," was conducted to provide information usable in answering environmental questions. The questions pertain to the potential environmental effects from oil pollution associated with increased tanker traffic, petroleum transfer operations, and refinery capacity anticipated for the next decade in the Puget Sound region. It was not intended to address the impacts of any specific proposed crude oil pipeline, refinery, terminal, or any other marine facility. The five-year project was one of many funded by the Environmental Protection Agency (EPA) predicated on the belief that development of our nation's energy resources need not be the precursor of widespread environmental damage and insult, which, too often in the past, accompanied resource development. This research project was administered by the National Oceanic and Atmospheric Administration's MESA (Marine Ecosystems Analysis) Puget Sound Project Office in Seattle, Washington.

Many of the same questions and concerns expressed in this report helped to shape and guide the Project throughout its lifetime. During the formative years, the Project goal and objectives were both generic in nature and formidable. The goal directed attention to the whole of the Strait of Juan de Fuca and northern Puget Sound, including passages through the San Juan Islands and tanker routes in Rosario Strait to Cherry Point, Ferndale, and Anacortes. When the Project initiated its first field studies in late 1975, the issues of crude oil superports and pipelines under Puget Sound had progressed beyond the visionary stage but had not surfaced for public debate and decision-making.

In July 1976, Northern Tier Pipeline Company filed an application with the State of Washington Energy Facility Site Evaluation Council to construct a crude oil terminal at Port Angeles, Washington, with a pipeline route to run round-the-Sound to Clearbrook, Minnesota. The issue of supertankers offloading at proposed superports at Cherry Point and Burrows Bay, or at enlarged facilities east of Port Angeles, was a topic of heated debate for the next two and one-half years. On October 17, 1977, the Magnuson Amendment to the Marine Mammal Protection Act of 1972 was enacted. The Magnuson Amendment, in effect, prohibited new or expanded petroleum receiving facilities east of Port Angeles and supported the concept of a single, major crude petroleum receiving and transfer facility at or west of Port Angeles.

In March 1979, Northern Tier Pipeline Company announced that it intended to change its original proposal and route the proposed pipeline under and across Puget Sound rather than around the southern end of the Sound, which had been the main consideration in the draft environmental statement prepared two months earlier by the Department of Interior's Bureau of Land Management. Also, in August 1979, Trans Mountain Oil Pipe Line Corporation submitted an application to the State of Washington Energy Facility Site Evaluation Council to construct and operate a crude oil marine terminal 18 miles west of Port Angeles at Low Point and lay about 148 miles of new pipeline under and across Puget Sound to connect with existing links at Edmonton, Alberta. These rapid changes of events during the life of the Project helped guide the Project. Nevertheless, the original questions and concerns about potential effects from oil pollution continued to steer the Project to its conclusion.

So what if oil entered the marine waters of the Strait of Juan de Fuca or northern Puget Sound? How would spilled oil compare in amount to that of petroleum-derived hydrocarbons that might already be there from other man-related activities? Will the oil remain in the environment for any length of time, or will physical, chemical, and biological processes come into play to disperse, transport, and degrade the oil? What shoreline areas and resources might be impacted and how long would it take to be flushed out to the Pacific Ocean? What biological resources are at risk and how long might they take to recover from the direct or possible long-term effects of oil pollution? These are some of the basic questions and concerns the Project attempted to answer.

The data base formed as a result of this research project represents the most comprehensive understanding of this part of the Puget Sound's environment ever assembled. Data now exist to assess future changes in oil pollution levels, predict the possible fate of spilled oil, identify what parts of the region are biologically important and what biological effects may occur as a result of an oil spill.

Though specific statements regarding the likely fate and effects of oil spills are impossible due to site-specific differences in environmental conditions, some general conclusions can be drawn from the findings.

It is apparent that most of the region is free of petroleum hydrocarbons. Though minor concentrations were noted near refineries, marinas, and harbors, these hydrocarbons were often nondetectable in areas distant from these facilities. Microbiological processes and sorption/sedimentation processes may not be of much importance in the short term regarding chemical changes in oil or removal of oil from the marine system. However, mechanical weathering of oil by waves may be important during a spill. Thus, oil spilled or leaked in protected or calm waters may remain relatively toxic and concentrated for sufficient lengths of time to impact plants and animals that come in contact with it.

Transport and dispersal of spilled oil would be caused by winds and water currents. Both winds and water currents, which vary with time and location, are very complex. Additional complexities are caused by the influences of river mouths, the tides, storms, and land masses, such as islands. The net flow of surface waters among the San Juan Islands is generally southward and that of the Strait of Juan de Fuca is generally westward. Thus, given these conditions, oil spills, especially those occurring in open water, would be expected to be transported westward out the Strait to the Pacific Ocean. However, a number of important features and processes in the region complicate these "normal" conditions and would tend to result in eastward transport of oil in the Strait. Strong eastward surface currents, that is, reversals of the normal westward flow, associated with coastal storms would transport oil eastward, possibly as far as Whidbey Island. Winds along the southern shoreline of the Strait are often from the west, particularly at Port Angeles, and thus would tend to move oil eastward along the shore. Numerous experiments and observations at Port Angeles confirmed that eastward transport of surface-borne materials such as oil would usually take place if spills occurred in or beyond the mouth of the harbor. Eastward transport along the shore to Dungeness Spit and beyond is possible.

Spills in the open water of the eastern Strait could go in most any direction, depending upon which way the tide was running, direction of winds, and whether the spill was at the bottom or on the surface. Oil spilled at or near the bottom could be transported southward into the Puget Sound main basin by the prevailing bottom currents. Because of the complex patterns of local winds, eddies, fronts, and other small-scale features, the chances of an oil spill escaping westward out the Strait without fouling the shore decrease greatly as the initial impact is moved eastward into the Strait.

Areas of the region that are most important to the biota are those that provide a suitable habitat for feeding, resting, breeding, rearing of the young, and protection from storms, predators, and human disturbance. Though all parts of the region are occupied by marine organisms, some parts appear to be especially noteworthy. Based upon the data gathered in these studies, the far western Strait/Cape Flattery area; the area bounded by Jamestown, Dungeness Spit, Miller and Quimper Peninsulas and including Protection Island; the Smith-Minor Island area; the Samish/Padilla/Bellingham Bays complex; the Cherry Point area; and the Boundary Bay area appear to be very important. These areas generally support the most dense populations of birds, mammals, fish, and invertebrates.

Among these areas, as well as throughout the entire region, certain shoreline habitat types are clearly most worrisome with respect to the effects of oil spills. These habitat types are sheltered marshes and sheltered tidal flats. They (1) are usually protected from winds and waves and thus are often muddy and accumulate algal and other organic debris; (2) tend to accumulate and bind up oil; (3) support highly concentrated communities of detritus-consuming organisms which are, in turn, food for many larger animals; (4) often, as in the case in the Jamestown area, support huge numbers of benthic invertebrates, nearshore fish, birds, and mammals; (5) are slow to recover from oil spills because oil becomes bound to the mud and organic particles and does not leave or degrade quickly; and (6) are difficult to clean up without causing further damage by heavy equipment.

Many of the areas and habitats that are both sensitive to the effects of oil and important to the biota studied are in the eastern Strait or in northern Puget Sound. They could be affected directly by activities that result in loss of habitat or by oil spills within each area. In addition, they could be affected by oil spills originating elsewhere being transported to these areas. For example, the sensitive and important area near Dungeness Bay and Protection Island could be adversely affected by construction activities and oil spills within that area, as well as by oil spills transported eastward along the shore from Port Angeles or from the western portion of the Strait. Commonly occurring westerly winds and eastward nearshore currents could transport spilled oil exiting Port Angeles Harbor to this area, resulting in possible damage or loss of biological resources there. Spills occurring in the western Strait during surface current reversal events could also be transported there in as little time as one to three days.

Though the resources in the region east of Whidbey Island were not studied, the Skagit Bay area is known to be highly important for marine birds, salmonids, macroinvertebrates, and marsh plants. Thus, it could be adversely affected by construction activities and oil spills if they occurred nearby.

The MESA Puget Sound Project, in concluding this environmental assessment, leaves behind many technical reports, papers, special publications, and products which have contributed to a greater understanding of the marine environment of this biologically rich and sensitive region. This knowledge has been the foundation for discussion of environmental impacts presented in Environmental Statements prepared by the Department of the Interior, Bureau of Land Management, and the Washington State Energy Facility Site Evaluation Council concerning crude oil transportation systems in the State of Washington. In addition, three NOAA scientists and five other Project-sponsored scientists provided expert testimony at Washington State EFSEC hearings in Olympia concerning the Northern Tier Pipeline Company's application to build a crude oil terminal at Port Angeles and pipeline over and under Puget Sound.

Still, because of time and budgetary constraints, many questions remain either partially or totally unanswered. We hope that future projects and related research will build upon this basic endeavor.

PRODUCTS

Products refer to special Project studies and publications, technical reports, professional papers, and journal articles. Some products were directed toward keeping the public informed on the activities of the Project and the NOAA products and services available in the Puget Sound region. Another product, the "Sensitivity of Coastal Environments to Spilled Oil - Strait of Juan de Fuca and Northern Puget Sound", will be a valuable guide to those responsible for directing the protection of coastal resources and the cleaning up of oil spills. Some products were aimed at organizing and storing the large amount of scientific data collected; this permitted rapid analyses and intercomparison of various data sets. Other products were designed to assist and guide Project scientists by providing comprehensive listings of historical and current research in the Puget Sound region. The purpose of all these products is to provide environmental and ecological information to resource managers, decision-makers, and concerned citizens in a format useful for management purposes.

PUGET SOUND BOOKS: A WASHINGTON SEA GRANT PUBLICATION SERIES

Nearing completion, the Puget Sound Publication Series will be 14 definitive volumes on the environment and resources of Puget Sound. The objectives of the series are (1) to provide environmental and ecological information to regional resource managers and decision-makers in a format useful for management purposes; (2) to develop public awareness of Puget Sound ecosystems, especially the major marine processes and resources; and (3) to develop public awareness of humankind's impact on Puget Sound ecosystems. Topics include the following:

1. physical and chemical properties of the Puget Sound
2. geologic setting of the Puget Sound basin
3. shoreline processes in the Puget Sound region
4. plankton populations of Puget Sound
5. finfish populations of Puget Sound
6. environments and habitats bordering Puget Sound
7. marine mammals and waterbirds of Puget Sound
8. recreational uses of Puget Sound
9. commercial harvesting of fish, shellfish, and seaweeds of Puget Sound
10. demographic patterns of the Puget Sound region
11. jurisdictions, management, and control of Puget Sound resources
12. industrial and municipal waste disposal in the Puget Sound region
13. transportation and related facilities in Puget Sound
14. history of Puget Sound as a resource

Two volumes will be published in 1981 followed by the remaining volumes in 1982.

Publication Availability:
Books will be available from the University of Washington Press.

Price: To be determined

DESCRIPTION OF RESEARCH ACTIVITIES by the MESA Puget Sound Project, January 1980

The Description of Research Activities is what its title implies. Activities sponsored by the MESA Puget Sound Project, both in the Strait of Juan de Fuca and northern Puget Sound areas, as well as the Puget Sound region, are described. Each entry contains, where appropriate, the title of the study, principal investigators, Project Office contacts, start and end dates, the purpose, research components, sampling methods, and location maps. Publications and availability are given.

Publication Availability:
National Oceanic and Atmospheric Administration
Office of Marine Pollution Assessment
7600 Sand Point Way N.E., Tower Building
BIN C15700
Seattle, WA 98115

Price: Free

COMPENDIUM OF CURRENT MARINE STUDIES IN THE PACIFIC NORTHWEST by the Oceanographic Institute of Washington

The 1980 *Compendium* contains descriptions of 867 NOAA and non-NOAA research projects under way in the marine waters of Washington, Oregon, and British Columbia. Project summaries, arranged in 14 major research categories are indexed by investigator, subject, geographic area, and both sponsoring and performing organizations. Data availability and publications information also are included. The following marine science disciplines are included in the *Compendium*: fisheries, pollution and water quality, marine biosystems, ecology, engineering, coastal zone management, and physical, chemical, biological, and geological oceanography.

Publication Availability:
No longer available from the Oceanographic Institute of Washington. Contact NOAA/OMPA - Pacific Office regarding availability.

PUGET SOUND MARINE ENVIRONMENT: AN ANNOTATED BIBLIOGRAPHY by Eugene E. Collias and Svetlana I. Andreeva, A Washington Sea Grant Publication, Seattle, 1977. 392 pp.

The bibliography contains 1980 annotated references to literature on the Puget Sound marine environment published prior to January 1977. Entries cover all the oceanographic sciences as well as topics such as pollution, history, planning and management, demography and socioeconomics, and transportation, industrial, and petroleum activities. Entries are indexed according to (1) oceanographic regions, (2) river drainage basins, (3) water and land usage, and (4) subject. The entries are arranged in the volume in alphabetical order using the first author's last name.

Publication Availability:
University of Washington Press

Price: $10.00

SENSITIVITY OF COASTAL ENVIRONMENTS TO SPILLED OIL - STRAIT OF JUAN DE FUCA AND NORTHERN PUGET SOUND by Erich R. Gunlach, Charles D. Getter, and Miles O. Hayes, June 1980. 76 pp.

This study was prepared by the Research Planning Institute, Inc., Columbia, S.C. A shoreline assessment technique was used to determine the susceptibility of the shoreline of the Strait of Juan de Fuca and northern Puget Sound to oil spill impacts.

An *Environmental Sensitivity Index* was defined for the study area which depicts shoreline sensitivity to oil spills on a scale of 1 to 10, with higher numbers indicating more sensitive environments. These values, indicated on 36 U.S. Geological Survey topographic maps covering the study area, can be used for pre-spill contingency planning and spill response activities to protect important resource areas. The index combines oil residence time (geological sensitivity) with anticipated biological inputs. Areas of special biological and socioeconomic significance are indicated on the maps.

Publication Availability:
Maps and reports can be viewed at:
NOAA/OMPA - Pacific Office
7600 Sand Point Way N.E.
Tower Building, Room 120
Seattle, WA 98115
Distribution copies not available.

DATA CATALOG FOR THE MARINE ECOSYSTEMS ANALYSIS PUGET SOUND PROJECT: DISTRIBUTION AND SUMMARIZATION OF DIGITAL DATA by the National Oceanic and Atmospheric Administration, Environmental Data Information Service, National Oceanographic Data Center

The Environmental Data and Information Service (EDIS) of NOAA processes and archives biological, chemical, and physical data in standardized formats (file types). More than 600 individual files representing 14 data types have been archived on magnetic tape for the Project. EDIS has prepared a catalog which summarizes the digital data sets acquired by the MESA Puget Sound Project and shows the locations where the data were collected. Supplemental information is provided by a listing of Project-sponsored publications for the Puget Sound area.

Publication Availability:
NOAA
Environmental Data and Information Service
7600 Sand Point Way N.E., Tower Building
BIN C15700
Seattle, WA 98115

Price: Free

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